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TABLE OF CONTENTS

Page

Global Water Cycle
Franklin Robertson, John Christy, Steve Goodman, Tim Miller, Dan Fitzjarrald, Bill Lapenta, and Shouping Wang 1

Basic Studies of Baroclinic Flows
T. L. Miller, S.-H. Chou, F. W. Leslie, H.-I. Lu, and K. A. Butler 5

Climate Dynamics Experiments Using a GCM Simulations
D. Fitzjarrald, F. Robertson, J. Christy, H. Lu, B. Sohn, and J. Srikishen 7

MAMS - High Resolution Atmospheric Moisture/Surface Properties (460-21-30-90)
Gary J. Jedlovec, Anthony R. Guillory, Ron Suggs, Robert J. Atkinson, and Grant S. Carlson 9

AMPR/SSMI Data Comparisons
Roy W. Spencer, Robbie Hood, and Frank LaFontaine 13

Atmospheric Aerosol and Doppler Lidar Studies
J. Rothermel, D.A. Bowdle, V. Srivastava, M. Jarzembski, D. Cutten, and E.W. McCaul, Jr. 15

Global Lightning Studies
Steven J. Goodman, Pat Wright, Hugh Christian, Richard Blakeslee, Dennis Buechler, and Greg Scharfen 19

WetNet Operations
H. Michael Goodman, Matt Smith, Vada LaFontaine, Frank LaFontaine, and Don Moss 21

Advanced Visualization Techniques
Mike Botts 25

Interactive Access and Management for Four-Dimensional Environmental Data Sets Using McIDAS
William L. Hibbard and Gregory J. Tripoli 29

Research on Diabatic Initialization
Akira Kasahara 33

Potential Vorticity Index
Albert Barcilon and Hengyi Weng 37

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Use of Satellite Data and Modeling to Assess the Influence of Stratospheric Processes on the Troposphere
Terrence Nathan 41

Nonlinear Feedbacks Between Stratocumulus and Synoptic-Scale Systems
John H.E. Clark and Hampton N. Shirer 45

Laboratory and Theoretical Models of Planetary-Scale Instabilities and Waves
John E. Hart and Juri Toomre 47

Airborne CW Lidar Measurements of Atmospheric Backscatter at 9.1 and 10.6 μM
William D. Jones 51

Electrification in Winter Storms and the Analysis of Thunderstorm Overflight Data
Marx Brook 53

NOAA Backscatter Studies
Madison J. Post 57

Computer Modeling of Pulsed CO_2 Lasers for Lidar Applications
Gary D. Spiers, Martin E. Smithers and Rom Murty 61

Beta Measurements
R.M. Schotland, A.J. Warren and O.M. Funariu 63

Remote Sensing of Water Vapor Features
Henry E. Fuelberg 65

Global Temperature Variations
Roy W. Spencer and John R. Christy 69

Deriving Earth Science Products from SSM/I
Frank J. Wentz 71

WetNet: Using SSM/I Data Interactively for Global Distribution of Rainfall and Precipitable Water
Edward J. Zipser and James P. McGuirk 75

Observing System Simulation Experiments for the Laser Atmospheric Wind Sounder Using a Global Spectral Model
Gregg Rohaly and T. N. Krishnamurti 77

Nonlinear Dynamics of Global Atmospheric and Earth-System Processes
Barry Saltzmann, Wesley Ebisuzaki, Kirk A. Maasch, Robert Oglesby, and Lionel Pandolfo 83

The Role of the Sea-Surface Temperature Distribution on Numerically Simulated Cyclogenesis During ERICA
William M. Lapenta, Donald J. Perkey, Carl W. Kreitzberg, and Franklin R. Robertson 85

Monitoring, Analyzing and Modeling Global Climate
John R. Christy 89

Tropical Pacific Moisture Variability
James P. McGuirk 93

South Pacific Convergence Zone and Global Scale Circulations
(NAS8-37127, July 1987-July 1991)
Observational and Modeling Studies of Heat, Moisture, Precipitation, and Global-Scale Circulation Patterns
(NAG8-836, July 1990-July 1993)
Dayton G. Vincent and Franklin Robertson 97

Synoptic/Planetary-Scale Interactions and Blocking Over the North Atlantic Ocean
Phillip J. Smith, Mary A. Uhl, Anthony R. Lupo, Gregory L. Lamberty, and Melinda Hunter 101

Agenda 103

N91
32661
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TITLE: Global Water Cycle

N91-32661

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RESEARCH OBJECTIVES:

This research is the MSFC component of a joint MSFC / Pennsylvania State University Eos Interdisciplinary Investigation: "The Global Water Cycle: Extension Across the Earth Sciences." The primary objective of this investigation is to determine the scope and interactions of the global water cycle with all components of the Earth system and to understand how it stimulates and regulates change on both global and regional scales.

There are three integrating priorities under which the research tasks are organized: (1) Documentation of Earth System state and change, (2) Focused studies on controlling processes, and (3) Integrated conceptual and predictive modeling. The near-term tasks in which MSFC is involved are:

(1) Spatial/temporal variability of atmosperic water vapor and condensate as revealed in SSM/I.

(2) Diagnostic assimilation of SSM/I data (and eventually other satellite data sources) into a consistent global analysis of water vapor and condensate.

(3) Diagnostic analyses of diabtic heating and E-P from global gridded analyses.

(4) Correlative analysis of MSU brightness temperature variability with other diagnostics of the intensity of the global hydrologic cycle.

(5) Creation of an optimal climatological precipitation and streamflow data set from multiple platforms.

(6) Evaluation of the CCM hydrologic cycle and tests of improved parameterization of deep and shallow convection and PBL.

(7) Investigation of the sensitivity of the CCM climate response to SST and land surface hydrology anomalies.

(8) Mesoscale and regional aspects of atmospheric/land surface interaction.

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

Discussion of research related to tasks (1) and (2) is presented below. Other tasks will be discussed in separate presentations during the review.

(1) Water vapor variability

To analyze the space/time variability of SSM/I variables, a data set with uniform, synoptic sampling is desired. Unfortunately, because of the asynoptic nature of sun-synchronous orbits and non-overlapping swaths at tropical latitude this coverage is not available from the raw data. Significant progress has been made in applying Lagrangian methods to interpolate the data into a synoptic format. In studying lag correlation statistics of the SSM/I swath data it is apparent that the propagation (phase vector) of synoptic disturbances is well related to lower tropospheric winds. A simple transport model was developed that uses lower tropospheric winds to horizontally advect water vapor or cloud water. The model uses a nudging term to update the analysis so that at at any (x,y) location the solution agrees exactly with the SSM/I observations. The evolving solution is sampled at regular time intervals to yield synoptic analyses of SSM/I variables. This data set can form the basis of bandpass analyses to isolate synoptic from longer term variability.

(2) Multi-phase water analysis

The analysis described above provides a synoptic mapping employing rather minimal adjustment to the SSM/I data. To derive a data set which yields consistent diagnoses of vapor, cloud and precipitation requires vertical structure as well. A model has been constructed that uses SSM/I observations as a constraint on an evolving 3-dimensional moisture field. The basic formalism for the 4-dimensional multi-phase water analysis (4-DMPW) is a diagnostic assimilation procedure. In this methodology, wind fields from ECMWF gridded analyses have been used to drive conservation equations for vapor, liquid and ice. These equations, which also use bulk parameterizations of microphysics (e.g., condensation, autoconversion, collection, precipitation evaporation and fallout) are updated, or constrained in such a way that where SSM/I observations are available, the analysis agrees to within measurement accuracy. The qualifier "diagnostic" means that the wind field and temperature are specified from the ECMWF analyses and not predicted by this constrained model.

Our initial investigations suggest that this methodology can provide realistic, 3-dimensional evolving fields of vapor and condensate. The moisture balance and vertical structure of condensate derived by this method makes use of the best moisture field (SSM/I), and is kinematically consistent with global wind fields and simple but fairly realistic bulk microphysics. We have also noted that, as expected, analysis results are sensitive to the quality of the specified vertical motion, and that current analyses of this variable are in need of improvement.

(3) Diabatic heating

An analysis of five-day mean global heating rates diagnosed from ECMWF gridded analyses has been published. This work, formerly supported under a different RTOP will be continued next year under Eos funding (see accompanying contribution by John Christy).

(4) MSU temperature analysis
(See accompanying contribution by John Christy.)

(5) Optimal precipitation and streamflow analysis
Multi-parameter radar measurements will play a large role in understanding the relationships between cloud microphysics, satellite imagery and rain rate. An examination of CP-2 data from the June 13, 1986 COHMEX case has shown that the drop size distribution varies significantly with storm life cycle stage. This has implications for sampling strategies for verifying or calibrating rain retrieval algorithms.

(6) CCM Hydrologic cycle
A preliminary analysis of the large-scale water vapor structure in the CCM1 (T42) was completed and presented at the NCAR CCM Workshop in 1990. Further use of the CCM1 will continue after resolution of problems arising from changing to UNICOS.

(7) CCM1 climate sensitivity to lower boundary forcing
(See contribution by Dan Fitzjarrald.)

(8) Mesoscale modeling of atmosphere/surface interaction
A version of the Biosphere-Atmosphere Transfer Scheme (BATS) has been linked to the LAMPS mesoscale model. Proposed studies with this coupled system are contained within a proposal for FY92 funding submitted under Climate Modeling NRA.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

The analysis of SSM/I moisture variability is currently focusing on the analysis of synoptic-scale variability. An analysis of intraseasonal behavior has also been started and will be completed this summer. The focus of the 4-dimensional multiphase water anlaysis will continue to be on diagnostic treatment of convection and the treatment of surface fluxes.

CCM-related research will encompass: (1) sensitivity studies with imposed SST anomalies, (2) experiments with observed SST forcing, (3) comparison of CCM moisture lag-correlation relationships to those from SSM/I, and (4) diagnostics of cloud radiative forcing and its associated generation of available potential energy.

PUBLICATIONS:

Robertson, F.R. and C. Cohen, 1990: Global analyses of water vapor, cloud and precipitation derived from a diagnostic assimilation of SSM/I geophysical retrievals. Preprints, Fifth Conference on Satellite Meteorology and Oceanography, Sept. 3-7, 1990, London, England.

Wang, S., 1991: Regional modeling of the eastern north Pacific marine boundary layer. *Mon. Wea. Rev.* (To be submitted).

Wright, P.D. and S.J. Goodman, 1991: A multi-parameter examination of a mesoscale convective system. Preprints, 25th International Conference on Radar Meteorology of the AMS, Paris, France, June 24-28, 1991.

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Basic Studies of Baroclinic Flows

Investigators:

N91-32662

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S.-H. Chou, NASA/MSFC
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K. A. Butler, NTI/MSFC

Significant Accomplishments During the Past Year:

1. Computations were completed of transition curves in the conventional annulus, including hysteresis effects. A paper has been published by T. L. Miller and K. A. Butler on the use of the model GEOSIM (developed by this investigator group) to compute the transition between axisymmetric flow and baroclinic wave flow in the conventional annulus experiments of Fein (Geophys. Fluid Dyn., 1973). Results agree very well with the experiments, including the prediction of hysteresis for the extreme upper transition curve in the free-surface case. The only nonlinearity required to accurately predict the hysteresis is feedback between a single wave and the azimuthal mean state. It was found that there is a small region of parameter space in which the steady axisymmetric solution is stable to infinitesimal disturbances, but a finite-amplitude wave can be maintained indefinitely. The mechanics of this process have to do with the reduction of the mean azimuthal jet by baroclinic energy conversion from the mean state to the wave (reducing the thermal wind, hence the jet itself) which in turn causes a reduction in the barotropic energy conversion and normalized friction (both energy sinks with respect to the wave), thereby allowing the wave to be maintained. It was found that the wave state in this region can be obtained either by first obtaining a wave state in the non-hysteresis region and then slowly changing parameters to those of the hysteresis region, or by perturbing the axisymmetric solution by a baroclinic wave disturbance of large enough amplitude.
2. Thorough testing and documentation of the GEOSIM code has been completed. A paper has been submitted to the Journal of Computational Physics. The main result given in that paper is the benchmarking of the code on the steady-amplitude baroclinic wave case of Williams (JFM, 1971). While the code obtains Williams' results when at least one harmonic is used in addition to the fundamental wave 5, the use of a single wave 5 results in a significant underprediction of the wave amplitude and its effects upon the mean state. It is pointed out that the latter result disagrees with that of Quon (J. Comput. Phys., 1976).
3. Drs. Miller and Leslie are continuing to review the Spacelab 3 results from the Geophysical Fluid Flow Cell (GFFC), and numerical modeling has been performed of many of the cases with horizontal temperature gradients as well as heating from below, with different rates of rotation. A new flow regime has been identified, with "banana cells" in the equatorial region and nearly axisymmetric rings in the polar region.
4. A numerical study of the lower transition to axisymmetric flow in the baroclinic annulus of Lewis and Koschmieder (Geophys. Astrophys. Fluid Dyn., 1988) was performed using GEOSIM. A paper was accepted by GAFD which challenges Lewis & Koschmieder's conclusions that hysteresis exists in that transition. The numerical results indicate that the apparent hysteresis is due to the experimenters not waiting long enough before concluding that the flow had equilibrated.
5. The first phase of the laboratory experiments using the MSFC annulus which imposes the horizontal temperature gradient on the lower surface was completed. A journal article documenting those results as well as numerical calculations on various aspects of the experiments has been accepted by the Journal of Fluid Mechanics.
6. A study of amplitude vacillation in the annulus experiments of Pfeffer et al. (JAS, 1980) has been started. The model GEOSIM is decidedly capable of simulating both amplitude

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and structural vacillation. Analysis of the model's output indicates that the amplitude vacillation is actually a kind of structural vacillation, in which the structural changes are in the vertical rather than the horizontal and hence have not been identified by the experimenters. The structural changes are a result of interactions between the wave and mean flow which result in drastic changes in the preferred mode of instability. A survey of parameter space has also found hysteresis in this phenomenon, including hysteresis in the amplitude of the vacillation, a very surprising result.
7. The study of the effect of topography on supercritical baroclinic disturbances has been completed. The resultant paper by S.-H. Chou and A. Z. Loesch has been accepted for publication in J. Atmos. Sci. This study uses a simple quasi-geostrophic model to investigate, analytically and numerically, the nonlinear evolution of baroclinic waves in the presence of surface topography. The topographic form drag competes with baroclinicity for the control of amplitude evolution and propagation characteristics of the various disturbance modes. The effectiveness of the topography to phase lock and equilibrate a given mode versus that of baroclinicity to propagate and vacillate that mode depends on the topographic height, its zonal structure and the level of superciticality.

Focus of Current Research and Plans for Next Year:

1. The analysis of the Spacelab 3 GFFC results and numerical modeling of that configuration will be completed. A paper will be written documenting the results and analyzing the fluid dynamics.
2. The model GEOSIM will be used to study flows in GFFC that may be more Earth-atmosphere-like in basic character. Experiments to be conducted in the future reflight of the apparatus will be suggested.
3. The model GEOSIM will be used to study increasingly nonlinear phenomena in baroclinic flows, concentrating on the conventional annulus configuration. A paper will be written on amplitude vacillation, and the relationship between hysteresis in wavenumber selection and time-dependent behavior will be studied.
4. Further laboratory experiments will be conducted in which we make quantitative measurements of the temperature field at the top of the MSFC baroclinic annulus. These measurements will provide a more quantitative comparison with the numerical model, and they will allow the study of long-term temporal behavior such as vacillation. Currently, the hardware for these experiments is being developed. Furthermore, a small amount of software development is required for the data acquisition system.

Publications:

1. "A numerical study of the onset of baroclinic instabilities in spherical geometry" by T. L. Miller and J. D. Fehribach, Geophys. Astrophys. Fluid Dyn., 52, 25-43 (1990).
2. "Hysteresis and the transition between axisymmetric flow and wave flow in the baroclinic annulus" by T. L. Miller and K. A. Butler, J. Atmos. Sci., 48, 811-823 (1991).
3. "A laboratory and numerical study of baroclinic instability in a cylindrical annulus with the temperature gradient imposed on the lower surface" by T. L. Miller and N. D. Reynolds, accepted in J. Fluid Mech. (1991).
4. "Comments on 'Convection in a rotating, laterally-heated annulus: Transition to lower symmetry' by Lewis and Koschmieder" by T. L. Miller, accepted in Geophys. Astrophys. Fluid Dyn. (1991).
5. "A fully nonlinear, mixed spectral and finite difference model for thermally-driven, rotating flows" by T. L. Miller, H.-I. Lu, and K. A. Butler, submitted to J. Comput. Phys. (1991).
6. "Supercritical baroclinic disturbances under the influence of topography" by S.-H. Chou and A. Z. Loesch, accepted in J. Atmos. Sci. (1991).

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Title: Climate Dynamics Experiments Using a GCM Simulations

Investigators: D. Fitzjarrald/MSFC
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Accomplishments in the past year:

The study of surface-atmosphere interactions has begun with studies of the effect of altering the ocean and land boundaries. A ten year simulation of global climate using observed sea surface temperature anomalies has begun using the NCAR Community Climate Model (CCM1). The results for low resolution (R15) have been computed for the first eight years of the simulation and compared with the observed surface temperatures and the MSU observations of tropospheric temperature. A simulation at higher resolution (T42) has been done to ascertain the effect of an interactive soil hydrology on the system response to an El Nino sea surface temperature perturbation. Initial analysis of these simulations have been completed

Plans for next year:

The results so far have highlighted the difficulties of comparing the results of two highly complicated nonlinear systems, even when they share some considerable similarities and some of the same boundary conditions. We will work in the coming year to develop diagnostic techniques and visualization methods to facilitate this comparison with the goal of developing improved parameterizations in the global climate models. Simulations of the earth system will be made using the GCM and the results compared with climate data sets that currently exist at MSFC, along with new data sets that are developed in the pre-EOS era. Surface hydrology, turbulent interchange at the surface, cloud radiative forcing and surface radiation balance are the processes that will be initially investigated. This work will support NASA objectives within EOS, TOGA-COARE, TRMM, ISCCP, and will enhance our understanding of the coupling between the atmosphere and its boundaries.

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MAMS - High Resolution Atmospheric Moisture / Surface Properties (460-21-30-90)

P.I. Dr. Gary J. Jedlovec, NASA
Mr. Anthony R. Guillory, NASA
Mr. Ron Suggs, NASA
Dr. Robert J. Atkinson, GE
Mr. Grant S.Carlson, USRA

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PAST WORK AND CURRENT RESEARCH ACTIVITIES. Multispectral Atmospheric Mapping Sensor (MAMS) data collected from a number of U2/ER2 aircraft flights have been used to investigate atmospheric and surface (land) components of the hydrologic cycle. Algorithms have been developed to retrieve surface and atmospheric geophysical parameters which describe the variability of atmospheric moisture, its role in cloud and storm development, and the influence of surface moisture and heat sources on convective activity. Techniques derived with MAMS data are being applied to existing satellite measurements to show their applicability to regional and large process studies and their impact on operational forecasting.

Currently data from the Cooperative Huntsville Meteorological Experiment (COHMEX) and follow-on flight data are under investigation. Data from the CaPE experiment in summer of 1991 over Florida will provide additional collaborative measurements to further refine the techniques and to study the development of convection over Florida. Beginning in 1992, data from both the MAMS and Wildfire spectrometers flown during STORMFEST will come under investigation.

Currents efforts have been focused in in seven areas.

1. Refinement of MAMS precipitable water retrieval algorithms. Development has continued on the Split Window Variance Ratio (SWVR) technique to derive integrated water content (precipitable water) in the column from MAMS data. Improvements to the technique include better cloud detection/elimination schemes and the use of various template sizes for variance computations. The SWVR technique is being applied to other (more recent) data sets for further evaluation. The new data sets present higher quality MAMS data (than past applications) which include better calibration and 10-bit digitization of the split window channels. This new data is improving the retrieval quality for precipitable water. A second technique developed for MAMS precipitable water estimation, the physical split window (PSW) technique, has had limited application to MAMS in the past because of poor absolute sensor calibration. The new data sets are providing opportunity to re-evaluate this technique, however. The application of both of these techniques to the retrieval of other atmospheric parameters (e.g., ozone) is being studied to investigate the structure and dynamics of mid-latitude storm systems.
2. Application of SWVR and PSW techniques to satellite data. Both the SWVR and PSW techniques are being tested on satellite data to show their application to regional and global scale moisture mapping. Results of using the SWVR technique on AVHRR data have been inconclusive thus far. The SWVR technique requires fairly high spatial resolution data over a region under which the atmosphere is invariant (homogeneous). Preliminary results seem to indicate that the SWVR technique can only be applied to AVHRR data in regions with relatively high moisture content because of the reduced sensitivity of the 12 micrometer channel to low amounts of water vapor. The PSW technique on the other-hand has been successfully applied to VAS data for a COHMEX case study. The results compare favorably with those of other VAS PW retrieval techniques. The PSW technique has the capability to produce finer scale moisture products than some other techniques because of its use of only the two split window channels on VAS rather than all 12 sounding sounding channels. This work has been performed in conjunction with scientists at Florida State University and has lead to the M.S. thesis of Mr. Anthony Guillory this year.
3. Variability of surface thermal measurements. The variability of land surface temperature (LST) and normalized difference vegetation index (NDVI) has been evaluated using

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multi-temporal MAMS measurements over the Konza prairie during FIFE (1987). FIFE offers a unique opportunity to study surface processes because of the extensive ground truth and other ancillary conventional and remotely sensed data. The MAMS work shows that significant thermal variability exists at small scales (less than a few kilometers) and varies a over short period of time. The differential changes with time are due to different underlying land use in the region. Sun-sensor viewing geometries also had significant impact on both the LST and NDVI calculations indicating that caution must be used when combining different data sets. This has considerable impact on future Eos and geostationary observations and those made at different times or large and changing view angles from polar orbiting satellites.

4. Relationship between moisture distributions and convective development. The COHMEX case studies are being used to investigate the relationship between convective activity and atmospheric and surface features in the region. MAMS data is being used to describe the mesoscale moisture environment and surface thermal forcing. Additional information about the surface (land, water, vegetation, terrain slope/elevation, etc.) is obtained from MAMS visible channels and from ancillary GIS information. These derived parameters are also being utilized in one and two dimensional modeling at Florida State University (Fuelberg) and at the University of Alabama-Huntsville (McNider) to further this diagnostic investigation.

5. MAMS Quick View System Development. The MAMS Quick View System (QVS) is a personal computer (PC) based image analysis and display system designed to provide an enhanced capability to evaluate MAMS data during an aircraft deployment. This need arises from the limited post-flight evaluation capabilities provided by Ames for the Daedalus scanner systems. The QVS offers the portability of a personal computer with the advanced analysis and display features of a mainframe image analysis system. The QVS is currently based on an AST Premium 486 personal computer with 10 megabytes of RAM and 1000 megabytes of disk space. An IBM OS2 operating system (version 1.3) is used along with a the PC version of McIDAS (5.0). With the addition of a few specialized software and hardware modules, the QVS provides locally many of the MAMS processing capabilities currently available on the Engineering Analysis and Data System's (EADS) McIDAS. Many of the system components have been integrated and will be fully tested during the CaPE experiment. The MAMS QVS will soon have the capability to display real-time MAMS data (telemetered from the ER2) during a flight. This capability should be available in FY92 and may provide a valuable resource to future ER2 flights.

6. ER2 Coordination for CaPE. The NASA ER2 activities for CaPE are being coordinated by MSFC. Five NASA or NASA supported instruments will be flown on the ER2 during a four and a half week period beginning on 16 July and running through 17 August. The deployment will be based out of Wallops Flight Facility at Wallops Island, Virginia were extensive support facilities exist for a program of this nature. The ER2 activities have become an integral part of the CaPE experiment because of the unique measurements being made from this platform. The ER2 will also require special interactions with other aircraft, the Doppler radars, and other ground based measurement systems. This activity is currently being coordinated with the ER2/CaPE personnel.

7. MAMS data set production for earth system science investigations. A number of MAMS data sets have been collected and provided to outside investigators for use in their own NASA funded (and other) research activities. The MAMS measurements provide unique multispectral-multitemporal measurements of surface and atmospheric parameters at high spatial resolutions. These data sets include thunderstorm imagery (sent to GSFC and used extensively at MSFC), SST measurements for ocean motion calculations (sent to B. Emery at U. of Colorado), many data sets for moisture and cloud mapping (sent to H. Fuelberg, Florida State University, and D. McNider, UAH), Konza prairie surface scenes (FIFE Information System, GSFC), and surface scenes (Smith, Florida State University).

Other Activities. Much planning work was done in preparation for MAMS and Wildfire for STORMFEST (February and March, 1991), and for ER2/DC8 involvement in TOGA/COARE.

PLANS: See technical plan/proposal sent to NASA Headquarters by Principal Investigator for analysis of MAMS data from CaPE and for use of MAMS and Wildfire in STORMFEST. The analysis plans include the following goals and objectives. The involvement in STORMFEST will require 15hours of ER2 flight time during February/March 1992. Deployment is likely out of

Kelly AFB in San Antonio, Texas.

CaPE:

1) Use data from several good cases of sea-breeze front development to quantify the moisture associated with the front, its time and space variability, and its importance to developing clouds and thunderstorms. Either the SWVR technique or the PSW technique will be used to derive integrate water content from MAMS. Similar moisture products will be derived from VAS (and AVHRR if available) to show the strengths and weaknesses of moisture mapping from satellite platforms. In situ measurements from the King Air aircraft along with CLASS soundings and PAM surface stations will be used to verify the remotely sensed water vapor products.
2) Local sources of heat and moisture which may be important for convective development will be evaluated with MAMS data by monitoring the land surface temperature (LST) and atmospheric moisture patterns over the central Florida area. These parameters will be compared to surface features to investigate cause and effect relationships between the measurements.
3) Along with AMPR data, the utility of combined passive visible, infrared, and microwave measurements will be evaluated to assess land use, vegetation mapping, and soil moisture estimation. Data from several clear surface flights will be used. The high resolution aircraft data will provide a unique opportunity to inter-retate visible, infrared, and passive microwave measurements. The results of the comparison will show the limits and expectations of similar analyses from coarser resolution satellite data.
4) MAMS data from various thunderstorm flights will be processes in support of the precipitation and lightning investigations with ER2 data. MAMS imagery will be remapped into common projections with other ER2 data and that of GOES to provide a comprehensive analysis of the structure of the convective storms.

STORMFEST:

The newly developed Wildfire spectrometer (Daedalus Enterprises, Inc. under a NASA Ames Research Center SBIR) will be used to map high resolution ozone and water vapor fields for STORMFEST. This proposed work is a demonstration effort to show the feasibility of mapping high resolution ozone fields (with passive IR techniques) and the importance of tropospheric/lower stratospheric ozone variations to the study of jet streaks and mid-latitude storm systems. The goals are:

1) to collect high quality Wildfire data in conjunction with other in situ and remote measurements available during the STORMFEST field phase (1 February - 15 March 1992),
2) to develop algorithms to retrieve total ozone content and compare with those from TOMS and HIRS (IR), and
3) along with water vapor imagery, use the ozone data to better understand the 3-dimensional structure and dynamics of jet streaks and frontal systems in a case study investigation.

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Jedlovec, G. J., R. J. Atkinson, M. W. James, and M. R. Smith, 1991: The MAMS Quick View System -2 (QVS2): A workstation for NASA aircraft scanner data evaluation. Preprints Seventh Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology. AMS, Boston, 198-203.

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Title: AMPR/SSMI Data Comparisons

Investigators: Roy W. Spencer/MSFC
Robbie Hood/MSFC
Frank LaFontaine/USRA

Significant Accomplishments for the Past Year:

The AMPR was flown for the first time with successful data collection over precipitation targets in Florida and off the Oregon coast. The AMPR met its expected performance levels, with very low noise (0.2 to 0.4°C) and relatively troublefree operation. Numerous rain cloud systems over land and ocean were overflown and the measurements at 10.7, 19.35, 37.1, and 85.5 GHz reveal a wide variety of microphysical conditions which exist within raincloud systems. Although predicted by radiative transfer model calculations from cloud model simulations, this diversity has not been observed before due to the poor spatial resolution of spaceborne microwave radiometers. Saturation of the 19.35 GHz rain emission signal was frequently observed in the oceanic rain systems, supporting the desirability of a 10 GHz channel on the TRMM microwave radiometer for sensitivity to the higher rain rates.

Focus of Current Research and Plans for Next Year:

The AMPR will have several modifications, including additional (orthogonal polarization) channels at 19.35 and 37.1 GHz, and the warm calibration target will be replaced with a much more thermally conductive design. The AMPR will be flown in CAPE in the summer of 1991 where the first research quality radar data will also be collected for comparison to the AMPR data.

Publications:

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Title:

ATMOSPHERIC AEROSOL AND DOPPLER LIDAR STUDIES

Investigators:

MSFC/J. Rothermel (PI), UAH/D.A. Bowdle, USRA/V. Srivastava,
MSFC/M. Jarzembski, UAH/D. Cutten, USRA/E.W. McCaul, Jr.

Significant Accomplishments in the Past Year:

The Aerosol/Lidar Science Group of the Remote Sensing Branch, Marshall Space Flight Center (MSFC), engages in experimental and theoretical studies of atmospheric aerosol backscatter and atmospheric dynamics with Doppler lidar as a primary tool. Activities include field and laboratory measurement and analysis efforts by in-house personnel, coordinated with similar efforts by university and government institutional researchers. The primary focus of activities related to understanding aerosol backscatter is the GLObal Backscatter Experiment (GLOBE) program. GLOBE was initiated by NASA in 1986 to support engineering design and performance studies of the NASA Laser Atmospheric Wind Sounder (LAWS), an Earth Observing System (EOS) facility instrument managed by MSFC. GLOBE is a multi-element, multi-institutional effort designed and scientifically directed by MSFC toward developing a global aerosol model to describe tropospheric "clean background" backscatter conditions that LAWS is likely to encounter. The accuracy of LAWS wind estimates will depend on the strength of the backscattered signals, which in turn will depend on the spatial distribution and physicochemical and optical properties of aerosols. Two survey missions were designed and flown in the NASA DC-8 in November 1989 and May-June 1990 over the remote Pacific Ocean, a region where backscatter values are low and where LAWS wind measurements could make a major contribution. The instrument complement consisted of pulsed and continuous-wave (CW) carbon dioxide gas and solid state lidars measuring aerosol backscatter in the 0.53-10.6 micrometer range, optical particle counters measuring aerosol concentration, size distribution and chemical composition in the 0.1-43 micrometer range, a filter/impactor system collecting aerosol samples for subsequent analysis, and integrating nephelometers measuring visible scattering coefficients in the 0.45-0.7 micrometer range. MSFC personnel from the Optical Systems and Remote Sensing Branches and supporting contractors were responsible for obtaining backscatter measurements at close range using CW lidars at 9.1 and 10.6 micrometers, the former being the primary design wavelength for LAWS. Supporting measurements included satellite observations of tropospheric extinction profiles in the near-infrared, surface observations of aerosols and dust transport, coordinated observations by airborne and ground-based lidars and aerosol samplers, and visible and infrared satellite imagery. The GLOBE instrument package and survey missions were carefully planned to achieve complementary measurements under clean background backscatter conditions. Special flight maneuvers were made periodically throughout the GLOBE survey missions to allow intercomparisons between the *in situ* and remote sensing instruments. Measurements of backscatter at 9.1 and 10.6 micrometers and aerosol physicochemical and optical properties were made routinely at flight level. The airborne measurements were coordinated with ground-based aerosol samplers and satellite-based extinction profilers in order to relate the airborne observations to these long-term, global-scale climatologies of physicochemical and optical properties. The processing of each measurement set has been the responsibility of the investigators who developed and operated the instrument. Periodic meetings of the GLOBE scientific working group have been convened to identify data processing priorities and case studies, assess instrument performance, present preliminary findings, and assess overall progress. The most important GLOBE result to date has been the identification of a persistent statistical background CO_2 backscatter distribution, with a surprisingly uniform backscatter mixing ratio throughout a deep tropospheric layer.

Focus of Current Research and Plans for Next Year:

The MSFC Aerosol/Lidar Science Group has begun the task of synthesizing into a global aerosol backscatter model the GLOBE DC-8 and supporting measurements of physical, chemi-

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cal, and optical properties covering *ten* different wavelengths. Processed data sets that have been quality-controlled and validated will be incorporated into the GLOBE data base at MSFC. The model will be applicable to the primary LAWS design wavelength of 9.1 micrometers as well as secondary design wavelengths. A primary analysis technique involves synthesis of the various GLOBE measurements through careful application of Mie theory, taking into account instrument limitations. Conversion functions are being developed to relate one aerosol property to another, for example, 1.06 micrometer extinction to 9.1 micrometer backscatter. Measured size distributions and chemical composition along with established values of refractive index are used to calculate aerosol backscatter coefficient at a desired wavelength. Key checks of the Mie theory calculations are made by comparing calculated aerosol properties with direct measurements.

Mie theory has been successfully applied to both pre-GLOBE calibration and atmospheric measurements with the MSFC continuous-wave (CW) focused Doppler lidars. Aerosol particles with known size, shape and refractive index were generated under controlled laboratory conditions and used as calibration targets. Calibration factors were obtained by comparing measured backscatter signals with those calculated from Mie theory using the known properties of the generated particles. Work is currently focused on intercomparing the CW lidar backscatter observations with backscatter calculated from near-real-time measurements of size-segregated aerosol chemical composition using a preconditioned laser optical particle counter (LOPC). When the operating characteristics of the LOPC are properly taken into account as well as the ambient relative humidity levels, agreement is found to within a factor three or better for the case studies identified to date. MSFC researchers will attempt to quantify the life cycles and the vertical, areal, temporal, and microphysical variability of the background feature. Detailed studies of satellite imagery and supporting meteorological data are expected to lend insight into the relationship between atmospheric dynamic and thermodynamic features, and aerosol backscatter distribution. Specific future in-house tasks will include: (1) completion of processing of the MSFC CW lidar measurements, (2) studies of the optical properties of aerosols generated under controlled conditions in the MSFC Aerosol Optical Properties Laboratory, (3) use of aerosol size distribution and chemistry measurements to extend theoretical backscatter predictions to wavelengths at which no direct measurements were made, (4) incorporation of GLOBE findings into simulation studies to assess impacts of measured and modeled backscatter levels on LAWS performance, (5) continued development and refinement of the global tropospheric backscatter model at LAWS primary and secondary design wavelengths through synthesis of the GLOBE program data sets, and (6) modifications to the CW lidar systems to enhance sensitivity and operating capabilities both in the laboratory and in the field.

The current focus of lidar studies of atmospheric dynamics is on the development of an improved airborne scanning Doppler wind measurement system. The motivation is to understand specific mesoscale processes that are incompletely resolved or are beyond the capability of existing ground-based and airborne research and operational sensors. The GEWEX Continental-Scale International Project (GCIP) and US Weather Research Program Stormscale Operational and Research Meteorology (STORM) program have been identified as opportunities in which MACAWS could make unique and synergistic measurements. Proposed fundamental mesoscale observations will contribute to a greater understanding of the role of the mesoscale, helping to improve predictive capabilities for mesoscale phenomena as well as parameterizations of sub-grid scale processes in global circulation models. A collaborative development effort is planned among the atmospheric lidar groups of MSFC (Optical Systems and Remote Sensing Branches), Jet Propulsion Laboratory, and NOAA Wave Propagation Laboratory. Instrument development and integration is planned for FY92-4, with first flights on the NASA DC-8 in early spring 1994. Existing lidar components, some already flight-qualified, will be exploited to minimize costs. Systems of similar design but with more modest capability were built and demonstrated by MSFC researchers in the early 1980's.

Publications:

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Jones, W.D., "Calibrating a continuous-wave (CW) focused CO_2 lidar for single particle mode (SPM) backscatter measurements," *Proceedings, Fifth Conf. Coherent Laser Radar*, 215, Munich, Germany, June 5-9, sponsored by Opt. Soc. Amer, (1989).

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Rothermel, J., W.D. Jones, D. Hampton, V. Srivastava, M. Jarzembski, "Airborne coherent continuous wave CO_2 Doppler lidars for aerosol backscatter measurement," *Preprints, 4th Airborne Geoscience Workshop*, Jan. 29 - Feb. 1, La Jolla, hosted by NASA, 235-236 (1991).

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Srivastava, V., A.D. Clarke, J. Porter, M. Jarzembski and D.A. Bowdle, "Comparison of CO_2 backscatter using Mie theory from aerosol measurements over Pacific Basin with lidar data," *Preprints, 7th Symposium, Meteor Observation Instrum.*, Jan. 14-18, New Orleans, sponsored by Amer. Meteor. Soc., J268-271 (1991).

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Title: Global Lightning Studies
Investigators: Steven J. Goodman, Pat Wright, Hugh Christian, Richard Blakeslee, Dennis Buechler, Greg Scharfen
Significant Accomplishments in the Past Year:

1. Global Studies

Focus and Progress

We are analyzing the global lightning signatures from the DMSP Optical Linescan System (OLS) imagery archived at the National Snow and Ice Data Center. Transition to analysis of the digital archive as it becomes available and compare annual, interannual, and seasonal variations with other global data sets (e.g., precipitation, SSM/I microwave signatures of ice, diabatic heating, global and regional synoptic patterns).

An initial survey of the quality of the existing film archive has been completed and lightning signatures have been digitized for the summer months of 1986-1987. Initiation of the digital archival process at the AFGWC is still being worked.

Plans

The film archive will continue to be digitized to produce the global lightning data base from 1973-Present. Plans are underway to archive digital OLS data over Central Florida during the CaPE field program, if the AFGWC archive is not yet begun, in order to permit OLS validation with ground based total lightning measurements near Cape Canaveral, intercomparisons with other data sets, and to have a developmental data set to build a prototype digital data analysis ystem at NSIDC and MSFC.

2. Process Studies

Focus and Progress

This research focuses on the relationships between 1) global and regional lightning activity and rainfall, and 2) storm electrical development and environment. Remote sensing data sets obtained from field programs conducted in the tropics and U.S. are used in conjunction with satellite/radar/ lightning data to develop and improve precipitation estimation algorithms , and to provide a better understanding of the co-evolving electrical, microphysical and dynamical structure of storms. This knowledge strengthens the utility of NASA's lighting mapper and lightning imaging sensors for GOES, EOS-A1, and TRMM.

Plans

Analysis of tropical and U.S. data sets continuing. A clustering and sensor fusion algorithm was developed for assigning lightning activity to its parent storm/system and has proved useful in objectively studying lightning and rainfall production by these storms. A five-year lightning/rainfall climatology has been assembled for the Tennessee Vallley and is being examined. Satellite/radar/lightning data sets are to be acquired and examined from different climatological regions. Intercomparisons with other rainfall estimates (VIS, IR, SSM/I) have begun. U.S. rainfall estimates from the WSI radar network will be used for algorithm validation and intercomparison.

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Publications:

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Goodman, S. J., D. E. Buechler, and P. D. Wright, 1991. Lighting-rainfall relationships. To be submitted to J. Appl. Meteor.

Goodman, S. J., and K. R. Knupp, 1991. Tornadogenesis via squall line and supercell interaction revisited: The 15 November 1989 Huntsville, AL tornado. Presented at Tornado Symposium III, Norman, OK, April 2-5.

Wright, P. D., and S. J. Goodman, 1991. A multiparameter radar examination of a mesoscale convective system. Preprints, 25th Conf. on Radar Meteorology, Paris, France, June 24-28.

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Title: WetNet Operations

Investigators:

H. Michael Goodman/ES44, Matt Smith/NTI, Vada LaFontaine/USRA, Frank LaFontaine/USRA, Don Moss/UAH

Significant Accomplishments in the Past Year:

WetNet is an interdisciplinary Earth science data analysis and research project with an emphasis on the study of the global hydrologic cycle. The project goals are to facilitate scientific discussion, collaboration, and interaction among a selected group of investigators by providing data access and data analysis software on a personal computer.

Support for the WetNet project in FY91 is provided by both RTOP funding and the Earth Observing System Data and Information System (EOSDIS) project. The RTOP funding covers WetNet research and applications development, while the EOSDIS funding supports data access, personnel costs, and system hardware procurement.

WetNet has many similarities to the design of EOSDIS. The WetNet system fulfills some of the functionality of a prototype Product Generation System (PGS), Data Archive and Distribution System (DADS) and Information Management System (IMS) for the Distributed Active Archive Center (DAAC). The PGS functionality is satisfied in WetNet by processing the Special Sensor Microwave / Imager (SSM/I) data into a standard format (McIDAS) data sets and generating geophysical parameter Level II (e.g., marine wind speed, total precipitable water, etc.) browse data sets.

The DADS functionality is fulfilled when the data sets are archived on magneto optical rewriteable cartridges and distributed to the WetNet investigators. The WetNet data sets on the magneto optical cartridges contain the complete WetNet processing, catalogue, and menu software in addition to SSM/I orbit data for the respective two week time period.

The WetNet menu and catalogue serve as a form of the IMS. Although the WetNet menu is not the model for the EOSDIS IMS it does provide an easy to use and learn interface. The menu utilizes function keys to step through the menu tree structure. The menu permits complicated or lengthy command structures to be

represented by a single key stroke. Despite the usefulness of the menu, it is not possible to provide all of the WetNet functionality within the menu, therefore, a command line interface is available for those procedures which cannot be conveniently represented within the menu.

The major accomplishments in FY91 (to date and near future) are:

1. Increased support to 39 WetNet science investigators. The following scientists are now apart of the WetNet project.

Dr. Bob Adler/GSFC
Dr. Philip Arkin/NMC
Dr. Eric Barrett/RSU
Dr. Bob Brown/U. Washington
Dr. Al Chang/GSFC
Dr. Bhaskhar Choudhury/GSFC
Dr. James Dodge/HQ
Dr. William Emery/U. Col
Mr. James Ferriday/U. Col.
Dr. Catherine Gautier/UCSB
Dr. Ken Hardy/Lockheed
Mr. Greg Hunolt/HQ
Dr. Tim Liu/JPL
Dr. Chis Neale/Utah State U.
Dr. Pete Robertson/MSFC
Dr. Dick Savage/Hughes
Dr. Eric Smith/FSU
Dr. Jeff Star/UCSB
Dr. Fran Stetina/GSFC
Dr. Ed Zipser/TAMU
Dr. John Alishouse/NESDIS
Dr. Richard Armstrong/NSIDC
Dr. Francis Bretherton/U. Wisconsin
Dr. Donald Cavalieri/GSFC
Dr. Alaine Chedin/Ecole Polytechnique
Dr. Robert Crane/PSU
Dr. Robert Eli/WVU
Mr. Gerry Felde/AFGL
Dr. Kevin Gallo/NCDC
Dr. Steven Goodman/MSFC
Dr. Tony Hollingsworth/ECMWF
Mr. John Janowiak/NMC
Dr. Alberto Mugnai/Inst. di Fisica Atmos.
Dr. Bill Olson/U. Wisconsin
Dr. Barry Rock/U. New Hampshire
Dr. Akira Shibata/MRI
Dr. Roy Spencer/MSFC
Dr. Graeme Stephens/CSU
Dr. Frank Wentz/RSS

2. Begun production of WetNet data sets on magneto optical cartridges. In FY91 the project has produced and distributed 3 magneto optical data sets (a fourth is a week away). Each data set contains approximately 500 MB of data, software, and documentation. The original goal of producing a data set every two weeks has not yet been achieved. At the present MSFC can generate a data set in about 3 weeks. The generation of a data set includes updating and improving the user interface, analysis software, and documentation. The combination of continually improving the software and documentation package and a one week (5 working days) turnaround for copying the data sets to the individual magneto optical cartridges (45 copies) is the cause of the 3 week data set production cycle.

3. Convened a WetNet Users Workshop at UCSB in February 1991. The workshop was attended by approximately 75 people. This attendance included WetNet principal investigators, supporting scientists, interested observers, EOSDIS

representatives and MSFC personnel. The workshop participants redefined the content of the data sets. The first data sets produced in FY90 and early FY91 contained both SSM/I antenna temperatures and geophysical products for each individual orbit. At the workshop the participants decided to change the content of the data sets to SSM/I *brightness* temperatures for individual orbits and geophysical products at the *browse* (i.e. reduced spatial resolution) resolution. The scientists also requested that the ability to produce geophysical products at full orbit resolution be provided within the WetNet menu and command structure.

The WetNet principal investigators also defined the several science topic working group affiliations. The following groups and their team leaders were identified:

Precipitation:	Eric Barrett
Winds:	Bob Brown
Water Vapor/Clouds	Frank Wentz
Snow and Ice	Al Chang
Land Processes:	Jeff Star and John Heinrichs
Ocean Processes:	Tim Liu

These groups are identifying consensus algorithms as well as joint scientific investigations for the application and validation of the algorithms.

4. Training workshop at Huntsville, AL on 5-7 June 1992. The fourth user training workshop will be held next week. The purpose of the training workshop is to introduce new WetNet participants to the hardware, software, and WetNet operating procedures.

5. McIDAS communications developed for use with the TCP/IP protocol. The University of Wisconsin was funded to develop the McIDAS communications software to work with the TCP/IP protocol. TCP/IP is a *de facto* standard for computer communications and is presently utilized by the NASA Science Internet (NSI). NSI is providing network communications to the WetNet investigators as well as communications to the Austrailian Bureau of Meteorology and NOAA/NESDIS.

Focus of Current Research and Plans for Next Year:

The primary emphasis for the remainder of FY91 is to generate WetNet data sets at an increased frequency. Operational bottlenecks have been identified and solutions are being devised and/or procured. Although all of the WetNet principal investigators have been trained (by 7 June 1992), not all have received the WetNet workstations. This is due to government procurement regulations of automated data processing (ADP) equipment. Those investigators who do not have their WetNet workstations should receive them within the next couple of months. Additional software and circuit boards will also be provided in FY91.

WetNet is currently ingesting the SSM/I data via tapes from Remote Sensing Systems. With the addition of the TCP/IP software on the MSFC computer system (expected in August 1991), WetNet will be able to ingest SSM/I data from NOAA/NESDIS in near real time and distribute the browse data sets over NSI circuits (bandwidth of 56 kbps) to the WetNet investigators. The use of the TCP/IP protocol will also allow WetNet to utilize the connectivity to the Austrailian Bureau of Meteorology for the ingestion of the GMS geostationary satellite images. Geostationary data (GOES, GMS and Meteosat) is not the cornerstone of the WetNet data sets but it an important auxiliary data set.

In FY92 additional investigators will be added to the research groups. User support at MSFC (documentation, help, connectivity) should be enhanced with the addition of new hire. The increase in the support personnel is necessary due to the volume of data sets and the number of investigators. Additional requirements will also be levied by the EOSDIS project. The increased user support and distribution of data sets should provide the investigators with the opportunity to conduct their planned research activities.

Another significant step that is currently being planned for FY92 is to move the WetNet processing at MSFC to a Unix-based platform owned by the project. This will give WetNet and the MSFC DAAC the flexibility to manage and operate the project in a manner that is consistent with the goals of WetNet and EOSDIS. Currently the institutional computer system is not Unix-based (a desire of EOSDIS) and too restrictive in its user connectivity and interface system. The effect of moving to a Unix-based computer for processing at MSFC will be the need to transport the WetNet code to Unix platform and to interface that to the OS/2-based WetNet computers. This effort will utilize McIDAS-Unix which is currently due for initial release at the end of FY91.

Publications:

Goodman, H. M., M. Smith, C. V. LaFontaine, F. LaFontaine, D. Moss, 1991: Earth Science Data Processing, Archiving, and Access at NASA/MSFC in the EOS era. *Seventh International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology*, New Orleans, LA, pp.219-223.

WetNet Data Set 87187 - contains SSM/I and auxiliary data and analysis software for the period 9 July 1987 through 19 July 1987.

WetNet Data Set 87201 - contains SSM/I and auxiliary data and analysis software for the period 20 July 1987 through 2 August 1987.

WetNet Data Set 87215 - contains SSM/I and auxiliary data and analysis software for the period 3 August 1987 through 16 August 1987.

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Title:

ADVANCED VISUALIZATION TECHNIQUES

Investigator:

Mike Botts/UAH

Significant Accomplishments

I was brought on-sight to NASA Marshall Space Flight Center's (MSFC) Earth Science and Application Division (ESAD) in June 1990, in order to evaluation the existing visualization environment at ESAD and to implement efforts to correct any deficiencies within this environment. Part of this year's efforts has concentrated on evaluating the scientific computing needs of the division scientists and determining whether the existing visualization environment provides the proper tools for meeting these needs. Some of the deficiencies have been corrected using "off-the-shelf" software available for the Silicon Graphics computer from various NASA facilities. Other deficiencies will need to be corrected by intense development efforts in the upcoming year. Much energy has been spent preparing for this development effort, so that development will occur in a highly directed fashion and within an integrated, flexible, and expandable environment.

a. Evaluation of Visualization Environment at ESAD. The visualization environment at ESAD consisted primarily of the McIDAS turnkey image display system (mainframe & PC), with minor supplemental application programs running on I^{2}S, Stardent, and PC platforms. Although some scientists were satisfied with the present visualization environment, many expressed moderate to extreme frustration with the lack of adequate visualization tools to meet their needs. The findings, as reported in Botts [1], are summarized below:

1. McIDAS provides many visualization needs, but not all;
2. Many scientists have abandoned McIDAS because of difficulties of use, or because it does not meet their needs;
3. Scientists often turn to uncoordinated and generally inadequate development on PC's to try to meet their needs;
4. Some advanced prototype tools have been developed on Stardent, but development has never progressed to a stage of a general useful tool;

Ineffective use or abandonment of existing visualization tools has resulted from:

1. Lack of Integration of Tools
2. Lack of User-Friendly Interfaces
3. Lack of Coordination & Archiving of Software Development
4. Incompatible Data File Formats
5. Lack of Simple Output to Video or Print
6. Tools Not Available to Meet Many Visualization Needs

b. Definition of Science Needs. Outside of specific needs by various scientists, general needs of scientists at ESAD include:

1. Ability to Easily Move Data Between Visualization and Analysis Tools;
2. Easy to Learn/Easy to Use Applications;
3. Ability to Integrate Different Data Types from Various Sources;
4. Ability to Interactively Probe and Analyze Data, Not just Visualize;
5. Flexibility to Quickly Add New Features into Existing Tools;
6. Balance of Hardware Environment Between High-Powered & Personal Workstations;
7. 3D important in Many Applications, Overkill in Others;

In addition, four major application needs have been recognized:

1. A general Image Processing toolkit, with easy links to other applications;
2. Ability to link and compare various multidimensional & multispectral datasets (see LINKWINDS program below);
3. Ability to integrate, and interactively visualize, compare, and probe various datasets related in 3D space and time (see MASS project below);
4. Ability to interactively visualize, correlate, and analyze time sequences of large global data sets (see GloVE project below);

c. Evaluation of Available Software/Hardware. It was determined that some of the immediate needs of scientists at ESAD might be met using "off-the-shelf" software running on the Silicon Graphics (SGI) computer platform. A SGI 4D/50G was obtained under lease in order to evaluate the feasibility of the SGI platform for future visualization development, as well as to evaluate the following available software:

1. ELAS - an image processing package developed at NASA Stennis;
2. LINKWINDS - a linked windows application, developed at NASA JPL, for evaluating and correlating multidimensional, multispectral datasets;
3. FAST - a Computational Fluid Dynamics (CFD) package developed at NASA Ames;
4. 4Dgifts - general purpose image manipulation routines provided by SGI;

In addition, Stardent Computer's Advanced Visualization System (AVS) was evaluated to determine its usefulness for meeting some of ESAD's visualization needs. Two prototype programs, Vis5D and VisGI, developed under contract at the University of Wisconsin's Space Science Engineering Center (SSEC), were also evaluated.

Some of these programs have proven useful as either long or short-term visualization solutions, whereas others provide conceptual models and sources of usable code for future development at ESAD.

In addition to hardware and software issues, much energy has been expended in evaluating solutions to data input/output between computers and video/hardcopy devices. An Abekas A60 video frame store unit, capable of grabbing or playing 720 frames at video rates, was brought into ESAD for evaluation (Meyer and Botts [3]). For color printing of computer generated images, the TOYO TPG3100 Thermal Printer and the Mitsubishi S340 Sublimation Printer, have undergone testing with Stardent, SGI, and McIDAS generated images.

d. Definition of Software Development Environment. The importance of developing within a flexible, integrated visualization environment (DAVE) was discussed in Botts [1]. In order that software

development at ESAD result in flexible, extendable, and portable code, much effort has concentrated on defining the standards and tools under which this development will proceed. Transfer of data between various file formats (e.g. McIDAS, SGI, X, PC-based, and YUV) has been accomplished. Candidates for Common File Formats (e.g. CDF, netCDF, and HDF) have been evaluated. Common Data Structures to be used at ESAD are being development and implemented (Botts [4]). Standards have been evaluated and selected for operating systems (ATT UNIX V), windowing systems (X/Motif), programming languages (ANSI C, C++, and FORTRAN 77), and 3D graphics libraries (SGI GL). A tool for building Graphical User Interfaces (GUI), UIM/X, has been evaluated and selected.

Focus of Current Research and Plans for Next Year

Intense development efforts will begin in June 1991, to solve some of the immediate and long-term needs of scientists at ESAD, as well as any scientist working with EOS data sets. Two primary efforts include the Multidimensional Analysis of Sensor Systems (MASS) and Global Visualization Environment (GloVE) programs.

GloVE is an extension of previous prototype development efforts at SSEC, and will allow the visualization, correlation, and statistical analysis of time sequences of large global data sets (e.g. MSU, SSM/I, ECMWF, ERB, ERBE, CCM, LAMPS, RAMS). MASS will provide 3D visualization and analysis of various data sets associated with ER-2 flights (e.g. MAMS, AMPER, LIP) and allow correlation of these data sets with SSM/I, GOES, MSU, and ground-based RADAR data.

In addition, future efforts will concentrate on the integration of UNIX McIDAS (Meyer and Botts [2]) and general image processing routines into the visualization environment at ESAD. Input and output between workstation and video/print devices will be simplified through the development of user-friendly modules, also to be integrated into the environment.

References

1. Botts, M. (January 1991). *Recommendations for Establishing a Data Analysis and Visualization Environment (DAVE) at the Earth Science and Applications Division, NASA Marshall Space Flight Center*, white paper submitted to NASA/MSFC/ESAD.

2. Meyer, P. and M. Botts (January 1991). *Summary report to Division on Video Capabilities and Needs*, report to NASA/MSFC/ESAD.

3. Meyer, P. and M. Botts (September 1990). *Suggestions for a UNIX Based McIDAS*, report to NASA/MSFC/ESAD.

4. Botts, M. (March 1991). *The Importance of Data Abstraction and Standard Data Structures in Visualization Development*, to be submitted to visualization conference.

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TITLE: Interactive Access and Management for Four-Dimensional Environmental Data Sets Using McIDAS

INVESTIGATORS: William L. Hibbard and Gregory J. Tripoli

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

Enhancements to VIS-5D

The VIS-5D (VISualization of 5-Dimensional data sets) system provides highly interactive visual exploration of large gridded data sets such as those produced by numerical simulations and volume scanning radars. VIS-5D can accomodate data sets containing up to 50 million grid points in a five-dimensional rectangle. For example, these 50 million points can be factored as 50 latitudes by 50 longitudes by 20 vertical levels by 100 time steps by 10 physical fields (pressure, temperature, specific humidity, U, V and W wind components, etc.). VIS-5D was written as a subsystem of McIDAS, and accesses data in McIDAS file formats, including 3-D grid files, map boundary files, and topography file.

Recent enhancements to VIS-5D include:

A) vertical cross sections that can be moved through a three-dimensional spatial volume interactively

B) an interactive three-dimensional cursor that can be used to retrieve earth or grid coordinates of depicted data

C) interactive placement of wind trajectories using the three-dimensional cursor, with trajectories calculated both forward and backward from a user specified space/time point.

Other enhancements are designed to support production of publication quality images, such as:

D) 2-D text labels which the user can place over the VIS-5D display, and which can be individually moved or deleted

E) the ability to select ribbons for depicting wind trajectories

F) the ability to select high-quality calculation of transparency and anti-aliasing.

VIS-5D is being used by scientists at UW-SSEC and at NASA/MSFC to view the output of their numerical simulations. Greg Triploi is using it to help develop a hurricane simulation running on the Stardent GS-2000, monitoring the simulation as it runs, diagnosing problems as they develop, and using the insight gained to modify and restart the simulation. VIS-5D is also distributed as freeware.

Development of the VIS-GI application

The VIS-GI (VISualization of Global Images) application has been developed around the MSU temperature anomaly data set produced by Roy Spencer and John Christy of NASA/MSFC. It stores the images in a compressed format, and decompresses them and remaps them in real time for animation. Thus it is able to store two channels of data over the 12 years from 1979 through 1990 in 5 day steps (876 total time steps) with global coverage at 2.5 degree resolution in about 22 megabytes of memory.

The global images are displayed in either a Mollwiede projection or mapped onto a sphere. The user can switch between these map projections, as well as enable/disable animation, enable/disable map boundary overlays, and select between channel 2 and channel 4 with immediate response. The images animate at up to 10 frames per second.

The application provides a color widget for interactively adjusting the false coloring of the two channels. The mouse may be used to control panning and continuous zooming of the Mollwiede projection, and rotation of the spherical globe. The mouse can also be used to select and drag a geographical point for calculation and display of a time series of image values. The time series display also serves as a context for mouse selection of animation bounds and current displayed time.

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Design of the VIS-AD system

The VIS-AD (VISualization for Algorithm Development) system will give scientists the ability to interactively develop and modify algorithms for analysis and diagnostics of spatial data sets such as images and grids. In particular, the VIS-AD system will provide interactive visualization of internal data structures of the user's algorithms, interactive control of algorithm execution, and interactive modification of algorithms. Thus VIS-AD will function somewhat like an interactive debugger, but will provide visualization of data rather than simply printing numerical values. VIS-AD will access McIDAS data files, and will adapt VIS-5D as a basis for its displays.

We have completed a detailed design for the data type definition and data display functions of VIS-AD, and have begun implementing these functions. We have also developed preliminary designs for the algorithm modification and execution control functions of VIS-AD.

Whereas VIS-5D and VIS-GI are highly optimized for particular types of data sets, VIS-AD will provide a very general analysis and visualization tool, as well as a tool for interactive development of algorithms for processing images and other geometric data sets.

Numerical Modeling Applications

The University of Wisconsin -- Regional Atmospheric Modeling System (UW-RAMS) has been fully implemented on the Stardent GS-2000 VIS-5D workstation to both execute numerical simulations and then visualize results. This was accomplished by adopting the McIDAS format as a standardized model output and then building software so that the model users can design visualization to meet their needs. The output may consist of any number of the basic predicted variables or functions of those variables. The output software was also designed to build the McIDAS output stream from any specified spatial increment of any specified subgrid area of any of the model's nested grids. This provides the flexibility to output highly detailed data for short high resolution visualization sequences or longer less detailed sequences. Several scientific experiments have already been run on the Stardent GS-2000. These experiments include the numerical simulation of polar lows, tropical cyclones and the Kuwait fires. The tropical cyclone studies were the first to utilize VIS-5D as an interactive tool for model analysis with startling success. In fact, a visualization of the model simulation was presented to the 19th Conference on Hurricanes and Tropical Meteorology held on 6-10 May, 1991 in Miami Florida to show how vertically propagating internal gravity waves influence hurricane genesis. The comments from scientists at the conference were unanimous that the 5D visualization helped them see things they previously labored to imagine or else never even considered. Since it has been implemented for routine use with UW-RAMS, the VIS-5D software has grown to be a tool which we can no longer live without. The VIS-5D software has also been implemented by Prof. John Anderson (of SSEC) as a routine output from his group's numerical simulations of convective downbursts and by Dr. Robert Auney of CIMMS for visualization of synoptic scale 4D satellite data assimilation model.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

Further enhancements to VIS-5D

We will work with scientists to define useful new features for VIS-5D. Some possibilities include:

A) decrease the response time to user selection of new iso-level contour surfaces for depicting fields
B) interactive retrieval of field values using the 3-D cursor
C) render plane slices as psuedo-colored images rather than as contour lines, which would be useful for highly textured radar data
D) render satellite images onto surfaces in the 3-D box
E) render 3-D grids as transparent fogs, as faster workstations become available
F) provide more flexible map projections in the 3-D box

G) provide arithmetic, differential and integral operators on 3-D grids to compute interactive diagnostics
H) increase the size of data sets which VIS-5D can address, though the development of a distributed VIS-5D which can directly access data stored on a supercomputer

Generalize and enhance the VIS-GI application

We will generalize VIS-GI so that it may be applied to climate data sets produced by scientists at MSFC and other institutions. We will also work with scientists to define interactive statistical capabilities for VIS-GI, such as:
A) the ability to select a geographic region and integrate values over the region
B) the ability to correlate values from different points and regions.

Implement the VIS-AD system

We will implement an initial version of the VIS-AD system, including data type definition, data display, interactive algorithm modification, and execution control.

Because of its ability to display arbitrary data types and its support for interactive modification of the algorithms which compute those data types, VIS-AD promises to be an extremely flexible visualization tool. Thus VIS-AD will give us a very quick way to implement many of the enhancements which we may define for systems like VIS-5D and VIS-GI.

VIS-AD is possible because of the constant increase in performance of workstations. However, we will work to optimize the efficiency of the VIS-AD data type definition and data display functions, and begin work toward an implementation suitable for massively parallel architectures.

Plans for Modeling Applications

As we gain experience using VIS-5D as the primary analysis tool, we expect to learn more of what will be needed to improve the VIS-5D software for use as presentation graphics and as an interactive analysis tool. One such improvement will be to enable the VIS-5D program to use high resolution topography of model simulations. The implementation of VIS-AD will enable us to restrict VIS-5D output to primitive variables while derived quantities are calculated on the fly by VIS-5D. These derived quantities will include all of the individual tendency terms important to the evolution of the simulation. Animated sequences of physical processes will provide new insights into the relationship between individual processes and storm evolutions and will doubtlessly power a revolution in the understanding of phenomena ranging from dynamic scale interaction to the formation of hail in thunderstorms.

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RESEARCH ON DIABATIC INITIALIZATION

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The objective of this research is to contribute to the improvement of the analyses of irrotational wind and moisture fields in the tropics through advancement in the technique of initialization by incorporating diabatic effects.

Significant accomplishments in the past year (May 1990–April 1991)

Estimation of the uncertainty of daily synoptic analyses in the tropics

In order to learn where weakness exists in the present objective analysis procedures, we have conducted the intercomparison of three different FGGE analyses produced by ECMWF (European Center for Medium-Range Weather Forecasts) and NMC (National Meteorological Center) for the period of 26 January to 11 February 1979. One notable finding is that, while FGGE has succeeded in describing the quasi-rotational state of the atmosphere, further improvement is necessary to accurately describe the diabatically driven irrotational circulations in the tropics (Kasahara and Mizzi, 1990).

Normal modes of Laplace's tidal equations for zonal wavenumber zero

In conjunction with the normal mode initialization procedure, it became necessary to investigate which form of normal modes is appropriate for the zonal wavenumber zero component. We compared the characteristic differences between the two sets, one derived by A. Kasahara [*J. Atmos. Sci.*, **35** (1978), 2043–2051] and another by Y. Shigehisa [*J. Meteor. Soc. Japan*, **61** (1983), 479–493]. This work was done jointly with Dr. H. L. Tanaka, University of Alaska, Fairbanks (Tanaka and Kasahara, 1991).

Tropical initialization to ameliorate the spin-up problem of precipitation forecasts

In order to ameliorate the precipitation spin-up problem (prediction models' inability to produce realistic precipitation rates at the beginning of the forecast period), we investigated the impact of a tropical initialization procedure on precipitation forecasts.

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The procedure is divided into the three components: 1) Application of diabatic nonlienar normal mode initialization (NNMI), 2) Modification of the initial divergence by incorporation of satellite imagery data [Kasahara *et al.*, *Mon. Wea. Rev.*, **116** (1988), 866–883], and 3) Modification of the moisture and temperature fields by the cumulus initialization scheme [Donner, *Mon. Wea. Rev.*, **116** (1988), 377–385]. Numerical experiments were conducted by running 10.5 hour forecasts (42 time steps), starting from various initial conditions after application of some combination of the three initialization components. A triangular-42 version of the NCAR global spectral model (CCM1) and its associated NNMI package were used. The results of a case study from reanalyzed FGGE Level III data show that 1) even if a good estimate of diabatic heating rates were available, diabatic NNMI alone would not solve the spin-up problem, 2) the adjustments of moisture and temperature using the cumulus initialization are essential to ameliorate the spin-up problem, and 3) the divergence adjustment, assisted by satellite imagery data, is beneficial when used in conjunction with the cumulus initialization and diabatic NNMI procedures (Kasahara, Mizzi, and Donner, 1991).

Focus of Current Research and Plans for Next Year

Improvement in the analyses of vertical velocity and water vapor fields in the tropics

Accurate analyses of large-scale vertical velocity and water vapor are needed to describe and to predict the weather systems involving cloud and precipitation processes. Although the current data assimilation systems are satisfactory in the Northern Hemisphere, the analyses of horizontal divergence and moisture are unreliable in the tropics and the Southern Hemisphere.

We need a revolutionary idea to improve the analyses of atmospheric state in the tropics. In fact, it has been noted that satellite temperature and humidity soundings (SATEMs) are no longer giving a significant impact on analyses and forecasts in the Northern Hemisphere, due primarily to large errors of SATEM data and to improvement in the prediction models used for data assimilation.

The idea we are pursuing is that the analysis quality of the rotational wind (or vorticity) and mass (or temperature) in the tropics will be improved through the synergetic effects of four-dimensional data assimilation, which will produce a better prediction of the vorticity by improving the analysis quality of the divergence and moisture.

Clearly, we need more accurate wind observations, and various new wind measurement techniques are coming on the horizon. Similarly, observational programs to

measure tropical rainfall, such as one being planned by the Tropical Rainfall Measuring Mission (TRMM), will improve our understanding of tropical convection activity, as well as obtaining diabatic heating information in the tropics. However, we should not delay our efforts to improve the analyses of the vertical velocity and moisture until then, since we can still ameliorate current deficiencies by using the vast amounts of infrared and visible radiometric imagery data, which have not be incorporated in the present objective analyses of meteorological data. For example, outgoing longwave radiation (OLR) measurements have long served as a proxy for tropical deep convection. Yet, this information has not been used routinely in operational meteorological analyses. Similarly, passive microwave measurements from the Defense Meteorological Satellite Program's (DMSP) Special Sensor Microwave/Imager (SSM/I) are a complementary data source for use in determining the column-integrated precipitable water and precipitation. Thus, we need to develop the method to utilize these untapped data.

We are currently developing a unified approach to diabatic initialization, including traditional diabatic NNMI and combining the adjustment procedures to the first-guess fields of temperature, horizontal divergence and moisture through incorporation of satellite radiometric imagery data, which provide proxy data of total precipitation. Since only the first-guess fields are modified, this approach can be adopted at operational centers in conjunction with the current data assimilation systems.

Publications

Kasahara, A., 1991: Transient response of planetary waves to tropical heating: Role of baroclinic instability. To appear in *J. Meteor. Soc. Japan*, **69**.

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—— , —— , and L. J. Donner, 1991: Impact of cumulus initialization upon the spin-up of precipitation forecasts in the tropics. Submitted for publication to ***Monthly Weather Review***.

Tanaka, H. L. and A. Kasahara, 1991: On the normal modes of Laplace's tidal equations for zonal wavenumber zero. Submitted for publication to *Tellus*.

N91
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Title: Potential Vorticity Index

N91-32672

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I. Significant Accomplishments in the Past Year

Potential vorticity (PV) is a significant dynamical tracer which could be linked to ozone measurements from satellite and, therefore, could be a NASA measured quantity.

1. We have accomplished the first part of the research supported by NASA grant NAG 8-760, and written up a paper entitled "Potential Vorticity Index Vacillation In The 78 - 79 Winter: Its Relation To Teleconnection Patterns", which was recently accepted by *Quart. J. Roy. Meteor. Soc.*

   Based on ECMWF FGGE IIIb data set in the 78 - 79 winter, we define a PV index, $I(Q)$, as a measure of the zonally averaged, mid-latitude PV gradient on the 300K isentropic surface in the Northern Hemisphere, and study the evolution of that index and its relation to teleconnection patterns of 500mb geopotential height anomaly.

   The time series studies of the PV index and other indices indicate that in the time domain there is a dominant period of about 14 days, at which the PV index and the eddy index exhibit a strong signal in their spectra and have good coherence. Such a strong signal in the 14-16 day periodicity, which has been previously observed by many authors in the tropospheric and stratospheric circulation, is not obvious in the time series of our parallel study using the zonal wind index as defined by Kidson (1985).

   The cross-correlation coefficients between the PV index and 500mb geopotential height anomaly, at each grid point in the Northern Hemisphere, bring out some major teleconnection patterns summarized by Wallace and Gutzler (1981): the North Atlantic Oscillation, the North Pacific Oscillation, and the Pacific/North American patterns. The existence and the phase relation of these patterns with the PV index cycle are seen from daily 500mb geopotential height maps during this period. Each pattern has two stages, corresponding to high and low PV index periods, separated by a time difference of a few days. The Scandinavian highs, including those over the Norwegian Sea, tend to occur at or a few days *after* the minimum of the PV index, while the Greenland highs and the northern Pacific highs tend to form at or a few days *before* the maxima of the PV index. It seems that the large scale highs in Northern Hemisphere in the 78 - 79 winter occur preferentially during the transition period from low PV index to high PV index. They occur

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mostly in an orderly fashion: Scandinavian high → Greenland high → Pacific high; this picture points to planetary waves propagating westward. Scandinavia and the Norwegian Sea may be a key area which affects global flow changes. The composite maps show that, in general, high and low index periods correspond to relatively "wavy" and "zonal" flows in mid-latitudes, respectively, especially over Atlantic and Europe. A similar study between the zonal wind index and the geopotential height anomalies does not reflect as many of the teleconnection patterns as the PV index does, even though the zonal wind index and the geopotential height anomalies are on the same pressure surface (500mb).

Based on our limited data analyses and the comparison with climatological studies by other authors, we have shown that the zonally-averaged isentropic gradient of PV may be a better index of the global circulation in the Northern Hemisphere winter and may reflect the existence of teleconnections between large active centers, as well as the transition from one stage of the teleconnection pattern to another.

2. We have obtained the main results for the second part of the research, which focuses on temporal and spatial variation of blocking and cyclogenesis in the 78 - 79 winter and its relation to *global* and *local* PV gradients, $I(Q)$ and $\delta(Q)$, respectively.

   We have performed complex EOF analyses, using the same FGGE data set for the 78 - 79 winter, for a representative high-latitude-band and mid-latitude-band geopotential height anomalies at 500mb, Φ_H and Φ_M, and PV gradient at 300K, $\delta(Q)$, at each longitude for the 3-month period.

II. Focus of Current Research and Plans for the Next Year

1. Complete the second part of the research:

(1) Do Fourier analyses for first three EOFs of Φ_H, Φ_M and $\delta(Q)$ at given latitude bands, and find the dominant wavenumbers and frequencies which are responsible for these EOFs.

(2) Compare the results from EOF and Fourier analyses. The comparisons will be used to explore the relations of blocking and cyclogensis with local and global PV gradients.

(3) Study the time dependence of the local PV gradients and relate it to the PV index vacillation cycles observed and described by WB (1991). Infer dynamical explanations for the features observed in that PV index cycle.

(4) Write-up the second part of the research and submit it for publication in the Fall 1991.

2. Pursue a similar research for the FGGE winter in the Southern Hemisphere. The comparison between the results for two hemispheres for this particular winter will help understand the difference in global circulations between these two hemi-

spheres. Since the grant NAG 8-760 will be terminated in March 1992, the research of the Southern Hemisphere is subject to the continuation of funding.

III. Papers and Presentations Supported by NASA grant NAG 8-760

1. Weng, H.-Y. and A. Barcilon, 1990: Potential vorticity index and its relation to blocking and cyclogenesis. *XV General Assembly of European Geophysical Society, 23 – 27 April, 1990.*
2. Weng, H.-Y. and A. Barcilon, 1991: Potential vorticity index vacillation in the 78 - 79 winter: its relation to teleconnection patterns. Accepted by *Quart. J. Roy. Meteor. Soc.*
3. Whitaker, J. and A. Barcilon, 1991: Type B cyclogenesis in a zonally varying flow. Submitted to *J. Atmos. Sci.*
4. Whitaker, J. and A. Barcilon, 1991: On the genesis of mobile troughs in the upper westerlies. Submitted to *J. Atmos. Sci.*
5. Weng, H.-Y. and A. Barcilon, 1991: Temporal and spatial variation of blocking and cyclogenesis in the 78 - 79 winter. (in preparation)
6. A. Barcilon gave talks about PV index in seminars at NCAR and on the role of PV in explosive cyclogenesis at University of California at Davis.

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N91
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Title: Use of Satellite Data and Modeling to Assess the Influence of Stratospheric Processes on the Troposphere

N91-32673

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Significant Accomplishments in the Past Year (1990-1991)

1. Stability of idealized and realistic atmospheric flows: a mechanism for explaining the origin of observed waves in the atmosphere.

Over the past forty years hundreds, perhaps thousands of linear stability studies have been carried out in order to explain the origin and structure of observed waves in the atmosphere. Of these studies only a small fraction have considered the stability of time-dependent, zonally varying flow or the influence of radiative-photochemical feedbacks on the stability zonally uniform flow. Yet, as described below, the stability of such flows may yield important information concerning the origin, structure and transient time scales of free waves in the atmosphere.

A. Stability of free planetary waves in the presence of radiative-photochemical feedbacks (Nathan and Li, 1991; JAS)

During the past year we have developed a beta-plane model that couples radiative transfer, ozone advection, and ozone photochemistry with the quasigeostrophic dynamical circulation in order to study the diabatic effects of Newtonian cooling and ozone-dynamics interaction on the linear stability of free planetary waves in the atmosphere. Under the assumption that the diabatic processes are sufficiently weak, an analytical expression was derived for the eigenfrequencies of these waves valid for arbitrary distributions of background wind and ozone volume mixing ratio (γ). That expression reveals the following: 1) the influence of meridional ozone advection on wave growth or decay depends on the wave and basic state vertical structures; 2) vertical ozone advection is locally (de)stabilizing when $d\gamma/dz$ (>0) <0, *irrespective* of the wave or basic state vertical structures; 3) photochemically accelerated cooling, which predominates in the upper atmosphere, augments the Newtonian cooling and is stabilizing.

The one-dimensional stability problem also was solved numerically for a Charney basic state (constant vertical shear and constant stratification) and for zonal mean basic states constructed from observational data characteristic of each season. It was shown that ozone heating generated by ozone-dynamics interaction in the stratosphere can reduce (enhance) the damping rates due to Newtonian cooling by as much as 50% for planetary waves of large vertical scale and maximum amplitude in the lower (upper) stratosphere. For waves with relatively large vertical scale and maximum amplitude in the lower to mid stratosphere and small Doppler shifted frequency, ozone - dynamics interaction in the stratosphere can significantly influence the zonally rectified wave fluxes in the troposphere.

For the summer basic state, adiabatic eastward and westward-propagating neutral modes having the same zonal scale emerge; both are confined to the lower stratosphere and troposphere. For these modes ozone heating dominates over Newtonian cooling, and

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the modes amplify with growth rates comparable to those of baroclinically unstable waves of similar spatial scale.

B. Stability of time-dependent zonally varying flows (Manney and Nathan, 1990; JAS)

We have examined the stability of a basic state consisting of a westward - moving wave and a zonal mean jet using a linearized, nondivergent barotropic model on sphere. The sensitivity of the stability of the flow to the strength and structure of the zonal jet was emphasized. We have shown that for certain westward-moving waves, inclusion of a very weak jet in the basic state can dramatically alter the stability of the flow. An examination of the energetics shows that some unstable disturbances depend almost entirely on zonal variations in the basic state for their existence. In cases where meridional variations of the basic state dominate the energy transfer, examination of basic state meridional potential vorticity gradients is useful in understanding the stability characteristics. At subcritical basic state wave amplitudes, addition of a weak jet, which by itself is stable, can change the meridional absolute vorticity gradient to resemble that for a supercritical basic state wave alone. Unstable disturbances then occur that have spatial structures and propagation characteristics similar to those for the supercritical wave alone.

For a basic wave state resembling the observed "two-day" wave alone, inclusion of an easterly (summer) jet in the basic state has a strong stabilizing influence. When a strong easterly jet is included unstable disturbances occur that have structures similar to waves observed concurrently with the "two-day" wave.

We have also shown a seasonal dependence in the stability of several westward - moving basic state waves.

Focus of Current Research

Our current research is focused on the following problems:

1. *Examination of the finite amplitude interactions among radiation, ozone, and dynamics.* The beta-plane model described under 1A above has been extended to provide a self-consistent set of equations governing the weakly nonlinear interactions between the ozone and dynamical fields. These equations are currently being analyzed to provide a better understanding of zonally rectified transports of ozone, heat, and vorticity in a continuously stratified model of the troposphere-stratosphere coupled system.

2. *Examination of the role of seasonal forcing in short-term climate variability.* A two - layer, weakly nonlinear baroclinic model was recently developed in order to study the combined effects of topography, seasonal forcing, and wave-wave and wave-mean flow interactions on short - term climate variability. Preliminary model results are currently being analyzed.

Plans for Next Year

1. Examine the linear stability of free planetary waves in the presence of radiative - photochemical feedbacks for *instantaneous* rather that climatological distributions of wind, temperature, and ozone.
2. Continue work on the role of seasonal forcing in short-term climate variability.

Refereed Publications (1990-1991)

1. Manney, G. L., and T. R. Nathan, 1990: Barotropic instability of westward-moving waves in realistic stratospheric zonal flows. *J. Atmos. Sci.*, 47, 19 pgs.
2. Howell, P., and T. R. Nathan, 1990: Barotropic instability of zonally varying flow forced by multimode topography. *Dyn. Atmos. Oceans.*, 15, 35-58.
3. Barcilon, A., and T. R. Nathan, 1991: Effects of wave-wave and wave-mean flow interactions on the evolution of a baroclinic wave. *Geophys. Astro. Fluid Dyn.*, 56, 59-79.
4. Nathan, T. R., and L. Li, 1991: Effects of ozone and Newtonian cooling on the linear stability of transient planetary waves. *J. Atmos Sci.* (in press).

Additional Personnel Involved in the Project (1990 - 1991)

Ms. Cathy Hamann (M.S., 1990. Thesis title: Linear and nonlinear stability of zonally varying flow.)

Mr. Long Li (M.S., 1990. Thesis title: Effects of ozone heating and Newtonian cooling on the stability of transient planetary waves.)

Ms. Mary Parlange (M.S. expected 1992. Thesis title: Influence of seasonal forcing on a multi-wave baroclinic system.)

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TITLE: Nonlinear Feedbacks Between Stratocumulus and Synoptic-Scale Systems

INVESTIGATORS: John H. E. Clark and Hampton N. Shirer, Department of Meteorology, Penn State University

STRATEGY:

Widespread regions of low-level marine stratocumulus can affect tropospheric weather systems by perturbing the patterns of both radiative cooling and the vertical transports of sensible and latent heat. In turn, these systems control, in poorly understood ways, the cloud distribution. In our renewal proposal of June 15, 1992-June 14, 1995, we plan an observational, numerical, and theoretical study of this interaction that was initiated under NASA Grant NAG8-780. We shall relate northern hemisphere satellite-inferred and ground-based stratocumulus distributions to the amplitude and phase of stationary and traveling lower and mid-tropospheric synoptic-scale waves. At the same time, numerical models will be developed and used to study the implications of the stratocumulus-induced diabatic feedbacks. These results will be compared with the above observations. We ultimately seek a parameterization of these effects that could be incorporated into global climate models. We envision supporting two graduate students.

PROGRESS DURING FY91:

We have collected wintertime and springtime stratocumulus observations for a number of 5-day periods. We find close correlations between the mean 850 and 500 mb trough positions and cloud over marine areas (Pavloski and Calkins, 1991). A linear study (Clark, 1991) of the radiatively-driven interaction between stratocumulus and synoptic-scale waves has been completed. Shallow surface-bound traveling waves are created that are strongly dependent on the phase relation between cloud and low-level flow. A nonlinear model (Kratz, 1992) is now under development that will permit a more detailed investigation of these interactions. Finally, a nonlinear study (Haar and Shirer, 1991) of the modification of the background flow by boundary layer roll vorticies has been revised for submission for publication.

PLANS FOR FY92:

The observational study will be expanded to cover more cases and longer periods. Mean and transient components of the cloud distributions and the synoptic-scale wind and temperature fields will be related on a regional basis. The linear study initiated in FY91 will be extended to include cloud-driven interactions via synoptic-scale modulations of cloud-topped turbulent boundary layer sensible and latent heat transports. The nonlinear model will be used to investigate very simple scenarios of, and parameterizations for, diabatic feedbacks between cloud and large-scale flow.

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Clark, John H.E., 1991: Radiatively-induced interactions between low-level stratiform cloud and synoptic-scale motions, Mon. Weath. Rev., submitted for publication.

Haack, T. and H. N. Shirer, 1991: Mixed convective/dynamic roll vorticies and their effects on initial wind and temperature profiles, J. Atmos. Sci., submitted for publication.

Kratz, B., 1992: Stratocumulus modulated quasi-geostrophic flows, MS thesis, in preparation.

Pavloski, C. and J. Calkins, 1991: A stratocumulus cloud climatology, Undergraduate Special Project, Department of Meteorology, Penn State University.

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LABORATORY AND THEORETICAL MODELS OF

PLANETARY-SCALE INSTABILITIES AND WAVES

May 10, 1991

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Meteorologists and planetary astronomers interested in large-scale planetary and solar circulations recognize the importance of rotation and stratification in determining the character of these flows. The two outstanding problems we are interested in are 1) the origins and nature of chaos in baroclinically unstable flows, and 2) the physical mechanisms responsible for high speed zonal winds and banding on the giant planets. The methods used to study these problems, and the insights gained, are useful in more general atmospheric and climate dynamics settings. Because the planetary curvature or β-effect is crucial in the large scale nonlinear dynamics, we have studied motions of rotating convecting liquids in spherical shells using electrohydrodynamic polarization forces to generate radial gravity, and hence centraly directed buoyancy forces, in the laboratory. The GFFC (Geophysical Fluid Flow Cell) experiments performed on Spacelab 3 in 1985 have been analysed. The interpretation and extension of these results have led us to construct efficient numerical models of rotating convection with an aim to understand the possible generation of zonal banding on Jupiter and the fate of banana cells in rapidly rotating convection as the heating is made strongly supercritical. Efforts to pose baroclinic wave experiments for future space missions using a modified version of the 1985 instrument have led us to develop theoretical and numerical models of baroclinic instability. Some surprising properties of both these models were discovered.

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RESEARCH HIGHLIGHTS: June 1990 - May 1991

BAROCLINIC FLOWS AND BAROCLINIC CHAOS

Linear instability calculations by Dr. T. Miller at MSFC have suggested that the GFFC should exhibit classic baroclinic instability at accessible parameter settings. Of interest are the mechanisms of transition to temporal chaos and the evolution of spatio-temporal chaos. In order to understand more about such transitions we have conducted high resolution numerical experiments for the physically simplest model of two layer baroclinic instabitity. This model has the advantage that the numerical code is exponentially convergent and can be efficiently run for very long times, enabling the study of chaotic attractors without the often devastating effects of low-order trunction found in many previous studies.

Cattaneo and Hart (1990) showed that there are a countable infinity of invariant manifolds in spectral space. This means that for a given set of external parameters that there are potentially an infinity of possible distinct statistical equilibria. In practice most of these are unstable, but numerical studies have shown that for parameters relevant to the atmosphere, at least two and more typically three or four states can be attained at large times depending on the initial conditions.

Numerical algorithms for implementing an Empirical Orthogonal Function (EOF) analysis of the high resolution numerical results were completed. The numerical model requires of order 64^2 spectral modes in each layer. These are linear Fourier harmonics. Low-order (e.g. 8x8) Fourier truncations don't even get the transition to chaos right! However, the EOF method is successful at replicating many of the high resolution complex simulations by obtaining low order descriptions based on the *nonlinear* orthogonal functions appropriate to the coherent structures in the original PDE calculations. Some of our 10^4 degree of freedom spectral numerical simulations can be reproduced by as few as 6 nonlinear ordinary differential equations for the amplitudes of the coherent structures. This method of reduction of a set of PDE's to a small number of ODE's provides a useful interpretive tool as well as an efficient predictive method. It provides a method for studying more complicated problems of climatic interest, including the effects of seasonal forcing on the level of internal variability and on the long-time evolution of model systems including nonlinear baroclinic wave transports.

COLUMNAR CONVECTION

Under conditions of rapid rotation and relatively low differential heating, convection in a spherical shell takes place as columnar "banana cells" wrapped around the annular gap, but with axes oriented along the axis of rotation. These were clearly evident in the GFFC experiments. Because the cells are aligned with the rotation axis, the simplest models for understanding their dynamics can be two-dimensional. There has been much recent effort to understand this type of 2-D convection. For example, Lin Busse and Ghil (GAFD, 45, 1989) use a spectral truncated low-order model to map out speculations about the transition to chaos. Lin (GAFD, 54, 1990) produced a low order model that generates *strong zonal banding* through the Reynolds stress associated with thermal convection in the presence of shear. This claim, which is offered as a mechanism for the banding on the giant planets, is in much dispute! Such bands were not seen in GFFC, although the parameters were different from those used by Lin. In an effort to resolve this dispute, a very accurate 2-D numerical model with resolution approaching 1024^2, was constructed. This model reproduces the GFFC results qualitatively. When extended to the cases studied by Lin no "double column instability" was found. The zonal flows were relatively weak.

Our recent numerical simulations of columnar convection contain several interesting results. First, the symmetry arguments of Cattaneo and Hart apply equally to this system, so there are at least two

independent *multiple states*. Indeed two of these were found numerically and their bifurcation trees (i.e. the transition to chaos) are being studied. The sideband instability of Lin et. al. does arise, though not at their truncated model's parameter values. Long waves propagate through the columns. In the chaotic states these intermittently organize the convection into larger vortex patches. This process may be related to the tendency for 2-D geostrophic turbulence to produce large isolated vortical structures, possibly leading to a strong zonal acceleration, a question that is still under study.

RESEARCH PLANS

We wish to further investigate nonlinear baroclinic flows. The initial success of the EOF method in producing a robust low-order system suggests an attempt to answer the following question. Under what circumstances can high resolution model results or laboratory data be represented by a low-dimensional model based on empirically determined nonlinear structures? What are the errors involved, data requirements, etc. Once a low order description is found, how can the low order structures be interpreted physically and perhaps arrived at beforehand from first principles?

These ideas shall be applied to the columnar (banana cell) convection models of circulation in the giant planets as well as to baroclinic instability. In both problems we shall pursue further the numerical simulations of transition to chaos, fractal behavior, and effects of additional realistic physical processes like time dependent forcing and small scale boundary layer turbulence on these processes. For example the transition to chaos and the nature of turbulent flow is strongly affected by the addition of a small amount of seasonal forcing. The dynamic origions of these effects are associated with the periodic forcing causing the system to locally approach homoclinic trajectories of the various invariant spectral manifolds in the system. A theory based on this idea, to be developed and verified by fully resolved numerical experiments, may lead to a better understanding of chaotic baroclinic wave systems.

RECENT PUBLICATIONS WITH NASA SUPPORT

Brummell, N., and Hart, J.E., "Numerical models of columnar convection" in preparation, 1991.

Cattaneo, F., and Hart, J.E., "Multiple states for quasi-geostrophic channel flows" *Geophysical and Astrophysical Fluid Dynamics*, **54**, 1 - 34, 1990.

Cattaneo, F., Brummell, N.H., Toomre, J., Malagoli, A, and Hurlburt, N.E., "Turbulent compressible convection" *Astrophysical J.*, **370**, 282-294, 1991.

Cattaneo, F., N.E. Hurlburt and Toomre, J., "Supersonic convection" *Astropohys. J.*, **349**, L63-L66, 1990.

Hart, J. E., "Experiments on planetary scale instabilities" *Nonlinear Ocean Physics*, ed. A. Osborne, 43 pages, Italian Physical Soc., in press 1991.

Hart, J.E., "Microgravity laboratory simulations of planetary and stellar circulations" *Microgravity Science and Technology*, **3**, 143 - 148, 1990.

Hart, J.E., "Finite amplitude baroclinic instability with periodic forcing" *Physica D*, **39**, 239-261, 1989.

Pratte, J.M., and Hart, J.E., "Endwall driven, low Prandtl number convection in a shallow rectangular cavity" *J. Crystal Growth*, **102**, 54-68, 1990.

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TITLE: AIRBORNE CW LIDAR MEASUREMENTS OF ATMOSPHERIC BACKSCATTER AT 9.1 AND 10.6 μM

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SIGNIFICANT ACCOMPLISHMENTS:

Atmospheric backscatter data collected during the GLOBE I and GLOBE II backscatter survey missions have been partially analyzed. These data were collected using the Marshall Space Flight Center's 9.1 and 10.6 μm focused continuous wave (CW) CO_2 coherent detection lidars. In general, both data sets have shown reasonably good agreement with data collected by the Jet Propulsion Laboratory's pulsed nadir and zenith viewing CO_2 system and with the ground-based, pulsed CO_2 system operated by NOAA's Wave Propagation Laboratory. Generally good agreement was also noted with IR backscatter estimates produced by Mie calculations using aerosol size and composition data obtained during the GLOBE I and GLOBE II missions.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

Analysis of the GLOBE I & II data sets is to continue. In addition, a series of laboratory experiments have been defined and partially completed to improve understanding of the performance of the signal analysis equipment. The results of these investigations will be invaluable in producing the final data sets to be submitted to the GLOBE data base.

PUBLICATIONS:

Refereed Publications:

Gras, J., Platt, C., Jones, W., Huffaker, R., Young, S., Banks, S. and Booth, J., "Southern hemisphere tropospheric aerosol backscatter measurements -- implications for a laser wind system." Journal of Geophysical Research 96, Number D3, 5357-5367 (1991).

Conference/Symposia Presentations:

Rothermel, J., Jones, W., Srivastava, V., Jarzembski, M., and Hampton, D., "*In-situ* backscatter measurements over the Pacific Ocean using two coherent focused CO_2 lidars." Proceedings of the 71st Annual Meeting of the American Meteorological Society, Paper J-14.2, New Orleans, LA, January 13-18, 1991.

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Hampton, D., Jones, W. and Rothermel, J., "A digital signal processing system for coherent laser radar." 7th Annual Technical and Business Symposium/Exhibition, Huntsville, AL, May 14-15, 1991.

Hampton, D. and Jones, W., "Design and performance of a digital signal processing system for coherent laser radar." Accepted for presentation at the 6th Topical Meeting on Coherent Laser Radar: Technology and Applications, Snowmass-at-Aspen, CO, July 8-12, 1991.

Rothermel, J., Jones, W., Srivastava, V., Jarzembski, M., and Hampton, D., "Remote tropospheric backscatter measurements at 9.1 and 10.6 micrometers with airborne focused Doppler lidars." Accepted for presentation at the 6th Topical Meeting on Coherent Laser Radar: Technology and Applications, Snowmass-at-Aspen, CO, July 8-12, 1991.

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Electrification in Winter Storms and the Analysis of Thunderstorm Overflight Data. NASA Grant NAG-066.

Principal Investigator: Marx Brook Prepared 15 May 1991

INTRODUCTION.

Until recently, electrification in winter storms has been observed only casually. Electrical activity is sparse, the lightning flashes are few and far between, and the number of winter thunderstorms is only a small fraction of those that occur in summer. Consequently, most lightning investigators have spent their winters analyzing summer data. The pioneering work of Takeuti et al.(1977) in Japan served to focus the attention of the international community on the existence of anamolous electrical effects associated with winter storms. In particular, the existence of positive return strokes of magnitude as large as 310 Coulombs was a new observation difficult to explain, especially since the Hokuriku winter storm clouds seldom exceeded 4-5 km in height (how do you fit so much charge into such a small volume of cloud ?). Positive lightning strokes were also found to be the dominant polarity of strokes in the Hokuriku winter storms (Brook, et al., 1981).

The emergence of 24 hr operational lightning detection networks has led to the finding that positive lightning strokes, although still much fewer in number than the 'normal' negative strokes, are also present in summer storms. Recent papers such as Goodman, et al.(1988) point up the importance of understanding the meteorological conditions which lead to a dominance of one polarity of stroke over another; in the paper cited the sudden appearance of positive strokes at the end of a storm appeared to presage the end-of-storm downdraft and subsidence leading to downburst activity. It is beginning to appear that positive strokes may be important meteorological indicators.

SIGNIFICANT ACCOMPLISHMENTS OF THE PAST YEAR.

1. DO THE NETWORK BLACK BOXES TELL THE TRUTH? Our initial effort on this grant was a study to verify that the "Black Boxes" used in the lightning networks to detect both negative and positive strokes to ground were telling the truth. After all, for more than 60 years scientists believed that ONLY negative charge was lowered to earth in return strokes.

We made waveform and polarity determinations with our own instrument operating side by side with the SUNYA LLP equipment. We found that, for lightning flashes within about 600 km of the SUNYA equipment the boxes gave the correct identification of stroke polarity. Only very occasionally did we have reason to believe that a pulse from an intracloud discharge was counted as a positive stroke. We were surprised to find, however, that for strokes occurring beyond about 700 km from the equipment, the polarity was generally wrong. Suffice it to say that for large distances over land the ground wave is often severely attenuated; the first ionospheric reflection suffers much less attenuation and arrives at the station with inverted polarity! This and other work related to determining stroke polarity from waveform measurements is discussed in the paper Brook et al., 1989.

2. SLOW TAILS CAN BE USED TO DETERMINE THE POLARITY OF DISTANT LIGHTNING. An outgrowth of this initial work on radiated lightning waveforms was the discovery that it is possible to determine the polarity of distant lightning correctly if the lightning stroke has a low frequency component, such as might be present in the long continuing-current strokes. The cutoff frequency for electromagnetic waves propagating in the earth-ionosphere waveguide is ~ 2000-3000 Hz depending upon ionospheric height. If the stroke has low frequency components, then the waveform as seen at distances of 500 km or greater from the source shows the attenuated VLF radiation components followed by a 'slow tail' propagating in the earth-ionosphere waveguide. We verified

that, for over one hundred cases, the polarity of the slow tail is the same as the original stroke polarity at the source. This result has important practical application since it is specific as to the frequency content of the stroke. Over 95% of the forest fires started by lightning are due to continuing-current strokes. An application for a patent is in progress (NASA Case MFS-26102-1).

3. LIGHTNING INITIATION IN WINTER vs. SUMMER STORMS. The most important results achieved to date relate to the electric field strength in clouds for winter vs. summer storms. We have been studying the initial breakdown phase of lightning in both strokes to ground and in intracloud discharges. What we find is little or no difference in the initial pulse activity associated with intracloud breakdown, but there is a striking difference between negative stepped leader development in winter vs. summer storms. Specifically, negative leaders in winter storms have a higher propagation velocity, are much shorter in duration, and exhibit E-field amplitudes which are often as large as if not larger than the return strokes which they precede. We interpret these characteristics along with other evidence to indicate that electric fields in winter clouds are considerably greater than they are in summer clouds. Since the electric energy stored in a cloud is proportional to the square of the electric field, we have here a possible explanation for a number of 'anomalous' features of winter storms.

Electric breakdown in clouds is determined not only by atmospheric pressure, but also by the presence of water drops under electric stress. At high values of electric field, water drops distort to ellipsoidal shape, and for high enough field values will go into corona and provide a copious source of ions to initiate a discharge (G.I.Taylor, 1965). Initiation will occur for electric field values well below the normal breakdown potential gradient of air. Thus, for dry air at NTP the breakdown potential gradient is ~30,000 V/cm, but in the presence of liquid water drops it will fall to values as low as 3000 to 10,000 V/cm, depending upon the radius of the drops. The presence of water drops in an electrified cloud can be thought of as providing an upper limit to the value of the local electric field.

Meteorological soundings taken at about the time of our winter storm data indicate that at the 4-6 km level (-10 to -20 deg C environment) the vapor pressure was close to saturation over an ice surface, indicating a dominance of solid rather than liquid form precipitation. We believe that the absence of large numbers of liquid water drops of size significant for lowering the breakdown potential gradient of air is the major factor in allowing the electric field to build up (whatever the mechanism) to values greater than those found in summer storms. The higher energy density achievable in winter storms would increase the probability that aircraft will trigger lightning upon penetration. It was the unusually high lightning related hazard provided by the shallow winter clouds off the sea of Japan which initially motivated the Japanese scientists to investigate the winter storms. A paper on the winter storms is now in an advanced stage of preparation.

4. INSTRUMENT DEVELOPMENT. We continue to upgrade our sensors for the measurement of electric field signals associated with lightning. We completely redesigned the Slow Antenna system to cure two problems: 1) the charge left on the flat plate antenna from blowing snow has been minimized by the use of an inverted 'salad bowl' housing which contains the 18" diameter plate and all the electronics; 2) Reduction of the input bias current to about .5 picoamperes has allowed us to use resistors as large as 10^12 ohms without suffering prohibitive offsets. The 10 second time constant and the high sensivity achieved allowed us to measure electrostatic field changes from as far away as 125 km. The wideband (.1 Hz to 2MHz) Slow Antenna sensor with the 12 bit 2MS/s digitizer is useful in studying simultaneously the radiation as well as the electrostatic fields of lightning.

5. OTHER ANALYSES IN PROGRESS. a) We are analysing lightning flash

records from storms between 40 and 125 km from the sensor. The ratio of electrostatic field, which varies as ~ 1/R^3, to the radiation field which varies as 1/R, for each stroke in a multiple stroke flash is of interest as a possible indicator of the distance R from the receiver. b) An interesting aspect of the initiation process involves the physical processes driving the stepped leader. In particular, the "turn on" and "turn off" aspects of the individual stepped leader pulses do not seem to fit accepted mechanisms. We are sorting through our summer storm lightning data to find several more good leaders from close storms.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR.

Our research objectives remain focused on the electrical aspects of winter storms, how they differ electrically from summer storms, and the association of changes in the cloud physical and dynamical environment with the onset or cessation of positive lightning strokes. We have been working on the hardware components for a second (and possibly a third) measurement station. Plans are to set up three stations, one at Albany, N.Y., one at Huntsville, and another at Socorro or Norman, Ok. We also plan to expand the data acquisition to two channels: 1) The regular E-field channel, and 2) an RF channel at ~ 250 MHz. The logarithmic receiver channel will provide us with complementary information regarding the lightning stroke initiation process.

Immediate plans for this coming year involve participation in the CAPE program at KSC during July and August. This work would also include cooperative observations with Dr. Vincent Idone on the electrical and optical properties of initial leaders during the ongoing lightning triggered program at KSC. Additional participation is planned with Dr. Richard Blakeslee at Huntsville to provide improved electric field instrumentation for the ER-2. We have also been in touch with the Marshall group regarding the implementation of a lightning monitoring station which would be used in conjunction with radar precipitation estimates for possible algorithm development relating lightning to precipitation as part of the ground truth activities of the TRMM program.

Multiple station measurements of winter storms are planned for this winter (probably late November through early January) with one station at Albany and the other at Huntsville. We are particularly interested in measuring the electrostatic field change involving continuing current strokes close to one station with the second distant station receiving the radiation waveform. This work will hopefully lead to identification of the source of the slow tail waveform. Since many of the large positive strokes in winter storms are accompanied by large continuing currents, we should be able to acquire the necessary data simultaneously at the two stations. We shall also try to arrange for recorded radar records of the winter storms along with the soundings in order to test our hypothesis that the fields within winter storm clouds are stronger than in summer clouds because of the nature of the precipitation mix.

PUBLICATIONS

1.Brook, M., Ron W. Henderson and Richard B. Pyle, Positive Lightning Strokes to Ground, J. Geophys. Res., 94, 13295-13,303 (1989)

In Preparation:Electrification in Winter Storms (Paper presented at Fall AGU meeting, San Francisco,Dec. 1989)

Ratios of Radiation Amplitude to Electrostatic Field Change in Multiple Stroke Lightning Flashes (Paper presented at Fall AGU meeting, San Francisco, Dec. 1990)

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TITLE: NOAA Backscatter Studies

INVESTIGATOR: Madison J. Post

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ACCOMPLISHMENTS:

In the past year NOAA has measured and analyzed another year's worth of backscatter over Boulder, Colorado. The average profile for the past year (Fig. 1) was computed from 80 observations of backscatter spread throughout the year, using NOAA's CO_2 coherent lidar operating at a wavelength of 10.59 μm. The seasonal averages (Fig. 2) show a familiar trend -- highest backscattering in spring (perhaps due to Asian dust or biomass burning) and lowest backscattering in fall. The 1990 average profile was not significantly different from the 1988 or 1989 profiles, except that it displays a slight increase in the upper troposphere, perhaps due to the Redoubt volcano.

A manuscript has been reviewed, modified, and resubmitted to Applied Optics on the observations of backscatter made from slopes of the Mauna Loa volcano in Hawaii over a 24-day period in fall, 1988. In that paper, a technique to better analyze backscatter observations with dropouts is presented, called the "inferred" technique. There was indication in the Hawaii data of a "background" mode of aerosol backscatter, similar to that reported by Rothermel, Bowdle, Vaughn and Post for NOAA's and RSRE's 1981-1984 backscatter data using a different method of analysis. However, that mode does not appear to be present when the 1981-1984 NOAA observations are reanalyzed with the inferred technique.

In October 1989 and May 1990 the NOAA lidar was used at NASA Ames to validate backscatter measurements being made by JPL's pulsed lidar (9.25 μm) and MSFC's CW lidars (9.11 and 10.59 μm) aboard NASA's DC-8 aircraft. These efforts, in NOAA's opinion, were crucial to the success of the 2nd GLOBE survey mission, having first identified instrument problems during the 1st mission, and then helping to confirm proper instrument performance during the 2nd mission. A NOAA observer was also aboard the DC-8 for the first two legs of the 2nd mission to aid the mission scientists in evaluating onboard lidar systems' performance.

Another accomplishment in 1990 was the refining of NOAA's backscatter processing program (BETA) to enable the calculation of gaseous absorption effects based on rawindsonde measurements, as well as by using atmospheric models. A NOAA Technical Memorandum on the revised BETA program is in press, describing in addition the entire procedure NOAA uses to process, archive, manipilate, and analyze the backscatter data gathered under this research effort. These procedures (and the necessary software) were developed under previous years' NASA funding.

NOAA participated in two intercomparisons of aerosol measuring instruments near Boulder, called FRLAB (Front Range Lidar, Aircraft, and Balloon experiment). The instruments were NOAA's CO_2 and ruby lidars, their King Air-mounted PMS probes and nephelometer, and the University of Wyoming's balloon-borne backscatter sonde. Intercomparison of all

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the data sources is possible using Mie theory, and preliminary results are encouraging. Ultimately, it is hoped that scaling factors can be developed to tie together historical records of the various instruments.

Finally, considerable effort was put into developing a multi-agency science proposal to NASA headquarters (MACAWS) to work with both JPL and NASA Marshall to produce an airborne Doppler lidar facility for the DC-8. This would enable NASA to make major contributions to dynamical science in large field campaigns such as STORM and GCIP.

CURRENT FOCUS:

NOAA continues to make routine backscatter observations at 10.59 μm near Boulder at the rate of 1-2 per week, and to process and archive those data. Comparisons of lidar backscatter with Mie predicted backscatter for thermally-conditioned particle size measurements in the 1988 Hawaii data are commencing, as well as studies on the representativeness of the Mauna Loa observatory samplers under upslope and downslope flows.

PLANS:

Routine observations of backscatter will continue to increase the climatological data base, and to help put future airborne and satellite observations of backscatter into context. Depending on funding of the MACAWS proposal, these observations may be curtailed for 6-12 months to implement hardware changes to the NOAA lidar. FRLAB intercomparisons will continue, with a publication likely in about 1 year. Studies on the representativeness of the observatory samplers at Mauna Loa will be published as well.

PUBLICATIONS:

1. Post, M.J. and R.E. Cupp, "CO_2 lidar backscatter profiles over Hawaii during fall, 1988," submitted to Appl. Opt.

2. Menzies, R.T. and M.J. Post, "GLOBE Backscatter: Climatologies and mission results," Proc. SPIE Symp. on High Power Lasers, 20-25 Jan., 1990, Los Angeles, CA.

3. Rothermel, J., D.A. Bowdle, J.M. Vaughn, and M.J. Post, "Evidence of a tropospheric aerosol backscatter background mode," Appl. Opt., 28, 1040-1042 (1989).

4. Post, M.J., " Atmospheric purging of El Chichon debris," J. Geophys. Res., 91(D4), 5222-5228 (1986).

5. Post, M.J., "Aerosol backscattering profiles at CO_2 wavelengths: the NOAA data base," Appl. Opt. 23, 2507-2509 (1984).

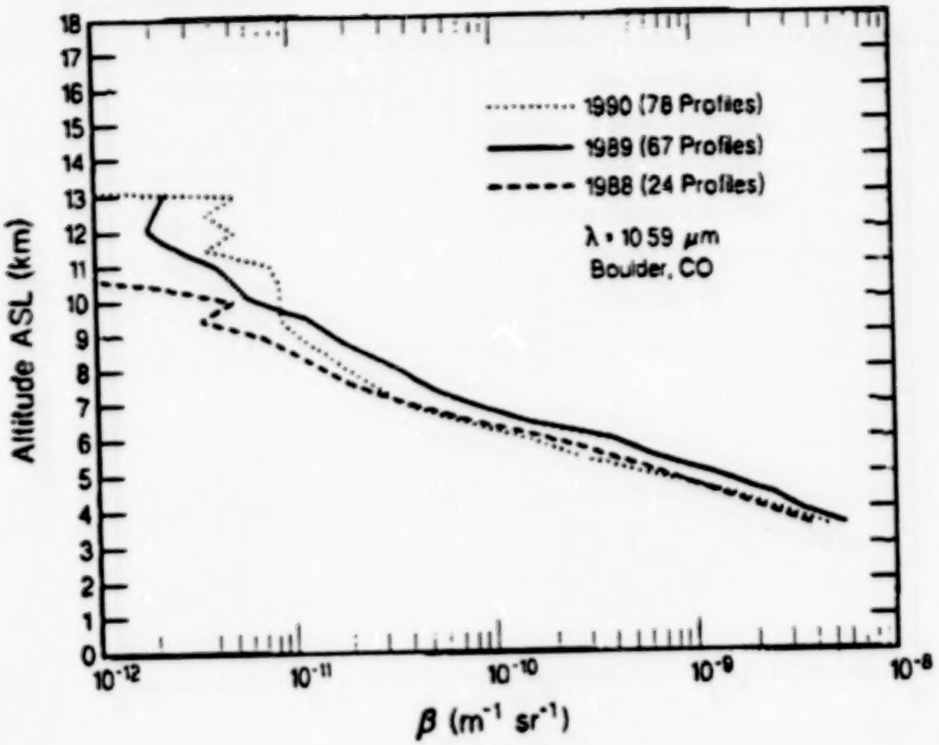

Fig. 1. Yearly averaged profiles of aerosol backscatter at $\lambda = 10.59\ \mu m$ over Boulder, Colorado, for 1988-90.

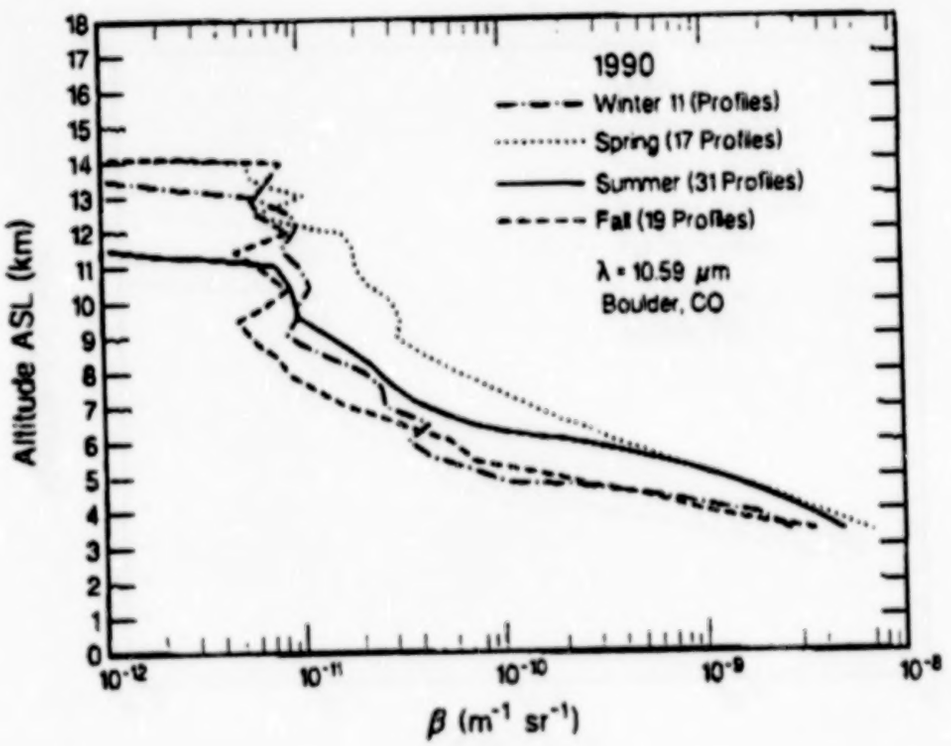

Fig. 2. 1990 seasonal averages of aerosol backscatter observed at $\lambda = 10.59\ \mu m$ over Boulder, Colorado.

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TITLE: Computer Modeling of Pulsed CO_2 Lasers for Lidar Applications

INVESTIGATORS: Gary D. Spiers, Center for Applied Optics, The University of Alabama in Huntsville, Huntsville, AL 35899, (205) 895 6030/(205) 544 3213.

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SIGNIFICANT ACCOMPLISHMENTS:

Allthough this modeling effort has only recently commenced, the experimental results obtained during the past year will enable a comparison of the numerical code output with experimental data to be made. This will ensure verification of the validity of the code. The measurements were made on a modified commercial CO_2 laser, the PSI LP-140. Results obtained included:-

1) Measurement of the pulse shape and energy dependence on gas pressure.

2) Determination of the intra-pulse frequency chirp due to plasma and laser induced medium perturbation effects. A simple numerical model showed quantitative agreement with these measurements. The pulse to pulse frequency stability was also determined.

3) The dependence of the laser transverse mode stability on cavity length. A simple analysis of this dependence in terms of changes to the equivalent fresnel number and the cavity magnification was performed.

4) An analysis of the discharge pulse shapes enabled the low efficiency of the laser to be explained in terms of poor coupling of the electrical energy into the vibrational levels. This analysis also provided estimates of the electron drift velocities and number densities.

5) The existing laser resonator code has been modified to allow it to run on the Cray XMP under the new operating system.

FOCUS OF CURRENT AND PLANNED RESEARCH:

A numerical model of a pulsed transversely excited (TE) CO_2 laser is being developed to enable the performance of such devices to be predicted prior to construction. This is of particular benefit to the LAWS contract where two contractors are providing alternative laser configurations.

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Although numerical models of TE CO_2 lasers have been used in the past these models have normally been constructed as several computer programs, each addressing a particular feature of the laser. Although a limited degree of feedback is available between these programs each is essentially a stand alone program and this lack of interaction between the modules resulted in limitations on the predicted output. This approach was necessitated by the considerable run time required by each of the programs. With the availability of much greater computing power, it has become possible to integrate all these modules into a single program where they can interact with one another.

The model addresses the transfer of stored electrical energy into the vibrational and rotational levels of the molecular gas species present in the laser gas and the subsequent conversion of the energy in these levels into the optical output pulse. The electrical to vibrational energy conversion will be modeled by solution of the Boltzmann equation with the inclusion of super-elastic and electron-electron collision processes which are normally excluded from the simpler models. Additionally a multi-line multi-mode gain distribution will be used to determine the optical output as opposed to the normal single-line single-mode approximation. The inclusion of hot band contributions to the gain together with modeling of the gas thermodynamic effects will enable the frequency content and stability of the output pulse to be determined as well as the output amplitude and pulse shape.

The model will be verified by comparison with experimental results obtained within the laboratory and from the published literature.

PUBLICATIONS:

1) Jaenisch, H.M. & G.D. Spiers,"Modifications to the LP-140 Pulsed CO_2 Laser for Lidar Use", SPIE High Energy Lasers Conference, Los Angeles California, Jan. 24, 1991.

2) Spiers, G.D.,"Discharge Circuit Considerations for Pulsed CO_2 Lidars", To be presented at the OSA Coherent Laser Radar: Technology and Applications Topical Meeting, Snowmass Colorado, July 8-12, 1991.

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BETA MEASUREMENTS N91-32681

Investigators: R. M. Schotland, A. J. Warren, O. M. Funariu

Significant Accomplishments:

This report covers the research undertaken during the second year of the BETA project. This program is divided into two areas (1) aerosol modification and climatology in the trade wind region and (2) the climatology of BETA(CO_2) on remote mountain top locations. These areas will be discussed separately in the following sections.

Aerosol modification and climatology in the trade wind region

Little information is available on the aerosol climatology of the marine free troposphere (MFT) in the trade wind region. This region, extending approximately 15 degrees either side of the equator, is characterized by a warm, moist conditionally unstable boundary layer capped by a strong inversion. Cumulus convection is wide spread throughout this region. The capping inversion limits the growth of these clouds which only rarely precipitate.

There is little land mass in the trade wind region and transport of aerosol from higher latitudes is also weak. As a result, the aerosol in this region are little influenced by land or anthropogenic sources. Trade wind cumulus convection is the likely source of aerosol modification and transport between the marine boundary layer and the MFT. An understanding of how these clouds transport and modify the aerosol should lead to a better understanding of the climatology of BETA for this region.

In order to study the effects of cumulus convection on the MFT values of BETA, a cloud model has been developed to simulate the evolution of a typical Pacific trade wind cumulus cloud. The stages involved in this development are outlined below.

A. Cloud microphysical equations have been developed. A paper has been submitted to JAS entitled "A Re-examination of the Derivation of the Equilibrium Supersaturation Curve for Soluble Particles" 8 April 1991.

B. Turbulence plays an important role in the mixing of outside air throughout the cloud. A closure method especially suited for gridded calculations, termed Transillient theory, has been developed by Stull and is used in this model.

C. The sulfur chemistry of the cloud droplets in relation to soluble gases (sulfur dioxide, ammonia, carbon dioxide, ozone, hydrogen peroxide, nitrous oxide, formic acid and formaldehyde) have been considered in detail. The cloud droplets are treated in twenty bins of one micron width.

Bistatic CW Lidar

The development of the bistatic lidar has proceeded more slowly than had been anticipated. The main reason for this delay was the death of Octavian Funariu, the student primarily involved in this portion of the research program. The accomplishments during the past year are as follows

A. The assembly of the major optical components of the lidar.

B. Tests have been run of the spectral bandwidth of the Synrad laser when a portion of the beam is mixed with a component which has traveled 450 meters corresponding to a delay of 1.5 microseconds. The bandwidth of the beat signal was measured to be 3KHz. This value corresponds to a velocity width of approximately 0.02 M/sec.

C. The data processing system has been completed. The system is based upon a parallel processing filter bank analyzer utilizing true time squaring detectors at each filter. The output of each filter is analog integrated and the output read by computer controlled A/D board.

Current Research and Plans for Next Year

Aerosol modification in Trade Cumuli

A. The numerical evaluation of the cloud model developed during year 2 will be completed. Tests will be performed on the turbulence algorithm employed in this model.

B. Questions exist concerning the residue that remains after the cloud droplet evaporates with respect to the back scattering cross-section. The simplest assumption (and the one normally assumed) is that the soluble components form a single sphere of uniform index of refraction. An attempt will be made to evaluate this hypothesis.

Bistatic CW Lidar

A. Assembly, testing and calibration of the lidar will be completed. A vertical scanning system will be developed using a folding flat. An attempt will be made to utilize a composite flat constructed from a front surfaced mirror, expanded aluminum hex and float glass epoxied sandwich. This technique has been used successfully in an earlier project.

B. The data processing system will be completed and tested. Algorithms to test the ability of the system to distinguish noise like signals from system noise will be developed.

C. The completed lidar will be taken to Mount Lemmon to obtain an extended data set of Beta(9.2 microns).

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REMOTE SENSING OF WATER VAPOR FEATURES

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Recent Accomplishments

Our current research has three major objectives:

1) Describe atmospheric water vapor features as functions of space and time,

2) Evaluate remotely sensed measurements of water vapor content, and

3) Investigate relations between fine-scale water vapor fields and convective activity.

We have been utilizing data from several remote sensors as part of this research. Our investigations utilizing the GOES/VAS, HIS, and MAMS instruments have provided a progressively finer scale view of water vapor features. Recent efforts have been focused in several areas:

1) VAS Evaluations--Error characteristics of VAS soundings have been examined. Olson (1990), Olson and Fuelberg (1990), and Fuelberg and Olson (1991) calculated agreements between VAS operational retrievals and radiosonde soundings, and between both versions of derived thermodynamic variables. Breidenbach (1990) and Breidenbach and Fuelberg (1990) evaluated time tendencies of VAS sounding variables. Each of these studies showed that VAS operational retrievals have serious deficiencies in sensing water vapor. Nonetheless, VAS products still can be used advantageously in some applications if special computational procedures are employed beyond those utilized operationally.

2) Simulated imagery--Muller and Fuelberg (1990) created simulated VAS 6.7 micron imagery by utilizing numerically predicted soundings from the LAMPS model as input to radiative transfer code. By comparing the simulated imagery to LAMPS' mass, moisture, and momentum fields, it was possible to better understand how the atmosphere produced the bands and swirls that were evident in the water vapor imagery. Brad Muller now is applying this methodology to the AMSU instrument. His current work is being sponsored by a NASA Graduate Student Researchers Program which allows him to work closely with Dr. Franklin Robertson and other scientists at NASA/Marshall.

3) VAS Case Studies and Algorithm Development--Fuelberg et al. (1991) used VAS retrievals to understand an event of sudden surface drying over central Tennessee during the summer. The VAS soundings used here were not the operational versions whose limitations were described above, but a special "research quality" data set that was prepared later. Results indicated that surface based mixing

penetrated a narrow dry tongue aloft. Intense thunderstorms formed along the periphery of the surface dry area.

Former graduate student Anthony Guillory has worked with Dr. Gary Jedlovec of MSFC to apply to VAS data Jedlovec's split window technique for calculating precipitable water. This algorithm is simpler and faster than many others, and it has produced very encouraging results (Guillory, 1991). Guillory was sponsored by a NASA Graduate Student Researchers Program--Minority Focus.

4) HIS Studies--Bradshaw and Fuelberg (1990) and Bradshaw (1991) have evaluated HIS interferometer retrievals prepared by scientists at the University of Wisconsin. Our efforts were an independent examination of the Wisconsin products. Specifically, HIS sounding data were compared against those from radiosondes, VAS, and MAMS; and the HIS retrievals were used to examine the causes of mesoscale cloud patterns. Results suggest that HIS will be an improvement over current filter wheel technology. However, since only two cases were investigated, additional studies are needed to fully explore HIS capabilities in diagnosing small scale water vapor features. The CAPE project offers this possibility.

Current Focus

Three research projects currently are in progress. The AMSU efforts of Brad Muller were described above. In addition, graduate student Mike Nichols is exploring a summer case over northern Alabama when MAMS indicated distinctive cumulus cloud patterns that appear to be related to topography and mesoscale circulations along the Tennessee River. To explore causes for the cloud features, precipitable water and skin temperatures are being calculated from MAMS imagery. In addition, a boundary layer model is being used to estimate growth of the mixed layer during the daytime.

A second MAMS study, by graduate student Rick Knabb, is utilizing MAMS data from a Pre-CAPE flight over Florida during October 1990. This case is characterized by strong north-south moisture gradients as well as outflow boundaries from previous thunderstorms. MAMS-derived thermal and moisture products are being used to explain cloud patterns during and after the MAMS flight.

Plans for 1992

The first objective is to complete the AMSU activities and the two ongoing projects involving MAMS. Conference papers and journal manuscripts describing findings will be prepared. As a second objective, we would like to draw on the experience we have gained with MAMS and HIS, by performing CAPE related investigations that utilize these data sources. Florida has an abundance of small scale circulations during the summer that can trigger convective activity (e.g., land/sea breezes, river/swamp/lake breezes, and outflows from previous thunderstorms). Our experience suggests that mesoscale water vapor and stability features also are present. Data collected during CAPE would be ideal for studying the capabilities of MAMS, HIS, and VAS for detecting these features and learning how they relate to thunderstorm formation. We will prepare a proposal for conducting this type of research.

Our second major research activity will investigate the new series of GOES satellites (GOES I-M) that will be launched by Spring 1993. GOES I-M will be superior to the current VAS system, especially in regard to moisture sensing. These new satellites will be the only geostationary platforms for moisture mapping for the remainder of this decade, and possibly for the next 15 years. Since a better understanding of atmospheric water vapor is the goal of a major new NASA research initiative called GVaP, our research will develop, evaluate, and use GOES I-M products in hydrologic studies, thereby permitting immediate progress toward the goals of GVaP.

Our objectives for the GOES I-M research are to:

1) Understand features in GOES I-M water vapor imagery and their relationships to horizontal and vertical humidity distributions and various kinematic/dynamic processes.

2) Quantify the accuracy, representativeness, and information content of GOES I-M imagery and products from that imagery, including temperature/dewpoint profiles, various measures of water vapor content and water vapor tracked winds.

3) Develop new procedures for examining atmospheric water vapor that take advantage of the enhanced capabilities of GOES I-M products over those now available from VAS.

4) As a result of the above, further the goal of improving our understanding of the role of atmospheric water vapor.

The proposed research will conducted jointly with Dr. Gary Jedlovec and other scientists at NASA/Marshall Space Flight Center. Jedlovec and Fuelberg have submitted a joint proposal to NASA Headquarters describing details of the research. Briefly stated, both observed imagery and simulated imagery prepared from a numerical prediction model and radiative transfer code will be employed. The use of simulated imagery will allow considerable research to be conducted prior to the launch of GOES I so that some findings will be available when the new satellite becomes operational.

Publications

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Title: Global Temperature Variations

Investigators: Roy W. Spencer/MSFC
John R. Christy/UAH

Significant Accomplishments for the Past Year:

Intercalibration statistics of all MSUs operating through 1990 were computed and brightness temperature anomalies on various space and time scales were compiled for MSU channels 2 (troposphere) and 4 (lower stratosphere). A tropospheric retrieval was developed through combination of channel 2 data from various view angles across the MSU scan swath to achieve cancellation of the influence of the lower stratosphere, and much of the upper troposphere, on that channel. Approximately twenty data sets were sent to various climate researchers for their research. Radiosonde validation of the MSU channel 2 and tropospheric retrieval anomalies was performed with ten years of data at all U.S.-controlled stations. It was found that the monthly 2.5^{o} gridpoint anomalies in TB computed from the intercalibrated satellites were very highly correlated with radiosonde-calculated TB anomalies, with correlations generally ranging from 0.94 to 0.98 and standard error of estimate of 0.15^{o}C in the tropics to 0.30^{o}C at high latitudes. It was found that use of a static weighting function and neglect of water vapor variations in the radiosonde calculations of TB degraded the standard errors by an average of only 0.02^{o}C. This means that a static weighting of various layer temperatures is sufficiently accurate for climate modellers to easily compute MSU channel 2 TB from their model output for comparison to the satellite data.

Focus of Current Research and Plans for Next Year:

Monthly updates of MSU data from NOAA will be processed at the end of each month and the derived datasets will be updated, along with satellite intercomparison statistics relating to noise and drift. An optical disk of all MSU temperature anomaly products will be produced and sent to the climate community.

Publications:

Spencer, R.W. and J.R. Christy, 1990: Precise monitoring of global temperature trends from satellites. *Science*, **247**, 1558-1562.

Spencer, R.W., J.R. Christy, and N.C. Grody, 1990: Global atmospheric temperature monitoring with satellite microwave measurements: Method and results, 1979-84. *J. Climate.*, 2, 1111-1128.

Spencer, R.W., and J.R. Christy, 1991a: Precison and radiosonde validation of satellite gridpoint temperature anomalies, Part I: MSU channel 2. Submitted to *J. Climate*.

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DERIVING EARTH SCIENCE PRODUCTS FROM SSM/I

Principal Investigator:
Frank J. Wentz
Remote Sensing Systems
Santa Rosa, CA

SIGNIFICANT ACCOMPLISHMENTS

There are three components to this project. The first is the production of a quality-controlled Level-1 data product for the SSM/I. Second is the generation of research-quality ocean products. The third component is studying the feasibility of obtaining both wind speed and direction from satellite microwave radiometers. The following paragraphs discuss the status of these three investigations.

Currently, four years of SSM/I sensor data have been produced. Time series of the SSM/I physical temperatures, receiver gains, and noise figures have been studied in order to access the stability and integrity of the sensor data. Algorithms for precise geolocation have been implemented to satisfy the requirements for ice edge location. Quality-control and editing routines have been developed to ensure an error-free Level-1 SSM/I product.

A physically-based retrieval algorithm is used to compute ocean products from the SSM/I Level-1 data. It simultaneously finds the near-surface wind speed, the columnar water vapor, and the columnar liquid water. These parameters are found by matching the SSM/I observations to a radiative transfer model of the ocean and atmosphere. The wind speeds have been compared to 3321 buoy reports, and the water vapor contents have been compared to 575 radiosonde flights. The rms differences for these *in situ* comparisons are 1.6 m/s and 0.31 cm, respectively. The algorithm has the ability to detect both light rain and a sea ice concentration of 5%. The ocean products are being used at approximately 30 institutions to study air-sea interaction, global change, moisture and heat fluxes, storms, and altimeter tropospheric correction.

A wind direction signal has been found in the SSM/I brightness temperatures (T_B). For moderate wind speeds, the v-pol upwind T_B is about 2 K higher than the downwind T_B. For h-pol observations, the T_B peak occurs at crosswind rather than upwind and is approximately 3.5 K higher than the downwind value. When this wind direction signal is removed, the rms difference between the SSM/I and buoy winds reduces to 1.3 m/s. The wind direction signal has been used to make global, low-resolution maps of the monthly mean oceanic wind vector. We have also begun a feasibility study on using a two-look satellite radiometer to measure the oceanic wind vector. Preliminary computer simulations indicate a wind direction accuracy of 15°.

CURRENT AND FUTURE RESEARCH

We are proposing to continue the production the Level-1 and Level-2 SSM/I products for another three years. This will result in a 7-year data set from which interannual variations can be studied. Water vapor, by itself, is an important Greenhouse gas, and the combination of water vapor and wind speed is a critical parameter in the estimation of latent heat flux and evaporation. A 7-year time series of these parameters in conjunction with the Microwave Sounding Unit (MSU) air-temperature time series being produced by *Spencer and Christy* [1990] will be of considerable value to global change studies.

A second SSM/I was launched in December 1990. We plan to cross-calibrate the second SSM/I with the first SSM/I. The cross-calibration must be done with extreme care to an accuracy better than 0.1 K in order to ensure that no artificial discontinuities are introduced into the ocean products time series. With proper cross-calibration, the seven SSM/I's to be launched during this decade should provide a time series of microwave radiances at the same accuracy as obtained for the MSU's (i.e., better than 0.1 K).

In addition to continuing the production of SSM/I ocean data, we will also continue our *in situ* comparisons. Thus far, only the first nine months of SSM/I products have been compared to *in situ*. We plan to extend the buoy and radiosonde comparisons to cover the entire 7 years of SSM/I data. This will give about 50,000 buoy comparisons and 6,000 radiosonde comparisons. This very large *in-situ* data set should provide a definitive statement on the capabilities of microwave radiometers to measure wind speed and water vapor.

We also plan to extend the SSM/I wind direction study. The two objectives of this extended study are:

1. Determine if a scientifically useful wind vector product can be obtained from the SSM/I's. If so, we would provide this product to the community.

2. Determine if a two-look radiometer can accurately measure the oceanic wind vector. If so, we would propose a design (i.e., noise figures, channel selection, scan geometry, etc.) for a radiometer wind-vector sensor that could be flown on future NASA spacecrafts.

To accomplish these objectives, we will first better determine the wind direction signal. The current results are based on 3321 buoy comparisons during the first nine months of SSM/I observations. To better characterize the signal, more buoy observations are required. As mentioned above, it will be possible to obtain about 50,000 collocated buoy-SSM/I observations for the 7-year SSM/I data set. Given this many comparisons, we should be able to well determine the wind direction signal and its associated variability.

Monthly global wind vector maps will be generated from the 7 years of SSM/I data. We will experiment with different methods for constructing these maps. One approach is to bin the SSM/I observations into monthly 5° latitude by 10° longitude cells. Possibly, better results on a shorter time scale can be obtained in areas where ascending and descending orbits crossover within 12 hours or less of each other. These wind fields will then be compared to fields coming from numerical models and from the ERS-1 Scatterometer (E-Scat). In addition, the SSM/I wind speeds can be used to validate the E-Scat wind speeds.

Finally, the simulations of the two-look radiometer need to be expanded. Thus far, we have done only a few simulations using smoothly varying wind fields. Realistic wind fields for a variety of mesoscale features should be considered, and various radiometer configurations should be tested. These simulations will determine the feasibility of obtaining mesoscale wind fields from a satellite microwave radiometer.

PUBLICATIONS

Wentz, F. J., L. A. Mattox, and S. Peteherych, New algorithms for microwave measurements of ocean winds: Applications to SeaSat and the Special Sensor Microwave Imager, *J. Geophys. Res.*, *91*(C2), 2289-2307, 1986.

Wentz, F. J., West coast storm forecasting with SSM/I, *RSS Tech. Rpt. 033190*, Remote Sensing Systems, Santa Rosa, CA, 378 pp. in 3 volumes, March 1990.

Wentz, F. J., A simplified wind-vector algorithm for satellite scatterometers, *J. Atmospheric and Oceanic Tech.*, to be published August, 1991.

Wentz, F. J., Measurement of oceanic wind vector using satellite microwave radiometers, submitted to *J. Geophys. Res.*, 1991.

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TITLE: WetNet: Using SSM/I Data Interactively for Global Distribution of Rainfall and Precipitable Water

INVESTIGATORS: Edward J. Zipser and James P. McGuirk

SIGNIFICANT ACCOMPLISHMENTS: N/A (Start date was April 15, 1991)

FOCUS OF CURRENT RESEARCH AND PLANS FOR COMING YEAR:

1. Complete hardware installation, prepare for comparative studies of SSM/I, radar, and lightning data. We believe that this will prove to be a powerful combination for evaluating the global distribution of tropical rainfall, and the vertical distribution of latent heating, with strong application to algorithms for use on TRMM, EOS-A, and future GOES spacecraft.

2. Survey potential data bases, identify about five case studies with surface rainfall, radar, lightning, and sounding data. Use SSM/I algorithms (initially at 85 GHz) to identify convective regions of MCSs. It is possible that exensive areas of very cold cloud tops in the GOES IR, often assumed to represent very deep and vigorous convection, may actually correlate better with active stratiform precipitation regions. It is important to know whether the convective and stratiform areas are well separated in space. We will evaluate several approaches to discriminate heavy convective precipitation from lighter stratiform precipitation, including but not limited to those of Adler and Spencer, whose algorithms are well suited to such real data comparisons. There is good reason to expect that the frequency of lightning in MCSs is closely related to the intensity of deep convection, and a good discriminator of the latent heating profile. We will develop a data base of lightning ground strike locations and frequency to begin adding this component to our research.

3. We will develop a catalog of the global distribution of heavy tropical rainfall, and how these zones are organized within larger tropical weather systems. Specifically, we will note the locations of apparent squall line structures. This would be an example of a first use of WetNet in extending knowledge of the distribution of mesoscale systems over the globe alone.

4. Beginning with the first few months of SSM/I data distributed over WetNet we will compare SSM/I radiances with TOVS radiances (moisture and thermal) and OLR observations. The purpose is to improve understanding of how real-world water vapor profiles in the tropical atmosphere are perceived by SSM/I precipitable water algorithm and, at the same time, by the TOVS water vapor channel. The PW algorithms can be used to deduce synoptic scale ascent and descent regions, and provide a context for the above studies, which are intended to discover the type of MCS and the precipitation distribution.

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Title: Observing system simulation experiments for the Laser Atmospheric Wind Sounder using a global spectral model

Investigators: Gregg Rohaly and Dr. T.N. Krishnamurti
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Introduction: Fundamental to improving the understanding of the total Earth system are increased and improved observations. In the coming decade several space borne instrumented platforms will be constructed and implemented. These platforms will, in large, be housing the NASA Earth Observing System (EOS) instrument suite.

One of the proposed instruments is a wind profiling system which is currently referred to as the Laser Atmospheric Wind Sounder (LAWS). This instrument will use a CO_2 Doppler lidar wind profiler to give wind measurements with a vertical and horizontal resolution which has yet to be seen globally. The LAWS instrument is now a candidate for launch on a NASA EOS–B platform and is fundamental to increasing our understanding of Earth System Science.

The importance of these improved wind data sets from LAWS should not be sold short. These data sets will form an integral component of the temporally continuous data base needed for research of the coupled climate systems. This instruments observations will aid in giving an improved description of the atmospheric circulation including the transports of energy, momentum, moisture, trace gases, and aerosols. Also, the wind data will be assimilated and used as the initial state for many global forecast models at various operational centers. Improvements in the forecast skill should be seen as well as enabling a forward progression of model development. In addition to the EOS–A platform instruments and the other proposed EOS–B instruments, LAWS wind measurements should help to advance our view and understanding of the total Earth system immensely.

Significant Accomplishments: Within the last year our group has worked toward assessing the impact the LAWS instrument will have on numerical weather prediction. This task has its limitations due to the lack of real LAWS wind observations. Therefore, observing systems simulation experiments (OSSE's) must be run so as to examine the impact. In these experiments one simulates a data set which is considered to be what the LAWS instrument would provide given that it was actually operational. This data set should idealistically be constructed so that it reflects the errors and inconsistencies that the instrument will have once it has been launched and is collecting wind measurements.

We have chosen to begin with the fundamentals and continuously improve upon them. Since few space borne platform OSSE's have been documented, a great deal of care and understanding is required to accurately attack such an important problem. We have chosen to begin with identical twin OSSE's using perfect winds for our LAWS observations. This is unrealistic in a sense, however, these early experiments have enabled a benchmark to be set showing the best case scenario for LAWS. These experiments have also aided in improving our understanding of how certain orbital parameters would affect global forecasts out to five days. A large amount of resources has gone into testing and development of the OSSE's. This includes the development

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of a multivariate optimal interpolation (OI) scheme and cloud obscuration techniques since LAWS is unable to see below clouds accurately.

An identical twin OSSE is run as follows: A numerical forecast model is integrated for a long period of time, generally 7 days or longer. This is considered the "nature" run and supposedly fully describes the atmosphere as 100% truth. As an example, from day five of the nature run, the u and v components of the wind field are interpolated to the latitude and longitude of the LAWS shot locations thus giving LAWS wind observations. The temperature, relative humidity, and height fields along with winds are interpolated to the positions of the World Weather Watch observations. These include rawindsonde, satellite drift winds, and commercial aircraft observations for a typical day's operational global coverage. Now having simulated these observations three dimensionally, a multivariate OI is used to create analyzed fields of height and u,v components. A univairate OI is used to do the temperature and relative humidity analyses. This routine is completed every six hours for a 24 hour period thus providing a full four dimensional data assimilation. The global spectral model is then run for five days to get the forecasts which had the LAWS data included in the assimilation. This entire process is duplicated except the LAWS observations are left out of the assimilation. The resulting forecast then shows the effects of only using the WWW data. This global spectral model run is termed the "control" experiment due to the exclusion of any LAWS observations. The impact of the LAWS instrument for a given set of orbital parameters can be seen by comparing the control run and the LAWS included run to the nature run.

These experiments show the differences in coverage which occur by varying the orbital parameters. Our group has found that there are large improvements in the forecasts especially over the oceans and in the southern hemisphere where there is a notable lack of wind observations. The polar orbit exhibits the most improvement globally, but repeatedly duplicates coverage in the polar region which can be considered a waste of resources. The 55° inclination angle orbit does not over sample the poles and provides more information from the tropical belt without greatly compromising the forecast skill as can be seen synoptically in figures 1a,b.

Future Experiments: Our plans for future work include doing some improvements to the identical twin OSSE's. Simpson Weather Associates, a fellow LAWS team member, is in the process of providing our group with data sets that add reality to the pseudo LAWS observations. The effects of aerosols, attenuation, backscatter and the inclusion of subvisible cirrus will be the most notable improvements in these data sets.

Also planned are fraternal twin OSSE's. These experiments will be done in the same fashion as the identical twin experiments except that one forecast model will be used for the nature run and to create the pseudo observations while a different model will be used to do the control and LAWS included forecasts. This type of OSSE is regarded to remove model biases and delete the effects of model climate drift.

We are now gathering information on other EOS platform instruments with the hope of including them with LAWS for some impact experiments on numerical weather prediction. Instruments which we are now considering include the Tropical Rainfall Measuring Mission (TRMM) rain radar, the Special Sensor Microwave Imager (SSM/I), the Atmospheric Infrared Sounder (AIRS) which will provide atmospheric temperature profiles, and the Stick Scatterometer (STIKSCAT) thus giving surface wind speed and direction over global oceans. These instruments along with LAWS will be used in OSSE's to examine their effect on global forecasting as well as on different model

parameters. We are hoping to see improvements in the transports of moisture and momentem as well as improving the prediction and affects of boundary layer fluxes such as sensible and latent heat and moisture. Together these instruments should provide a better defined initial state which will in turn improve forecast skill.

As our understanding of OSSE's continues to improve and develop, a switch to higher resolution models will be warranted. The future for OSSE's is to see how increased observations will aid in the forecasting of synoptic and especially mesoscale meteorological phenomena. For example, hurricane and typhoon forecasting as well as the overall structure of the smaller scale systems should become better defined.

Publications:

Krishnamurti, T.N., J. Xue, G. Rohaly, D. Fitzgarrald, G.D. Emmitt, S. Houston, and S. Wood, 1991: Using a global spectral model in an observing system simulation experiment for LAWS –an EOS wind measuring system. Preprints Second Symposium on Global Change Studies, New Orleans, La, Amer. Meteor. Soc., 23–27.

Krishnamurti, T.N., H.S. Bedi, K.S. Yap, J. Beven, and D. Oosterhof, 1991: Interpretation of typhoon recurvature dynamics from very high resolution global model forecasts. Preprints 19th Conference on Hurricanes and Tropical Meteorology, Miami, Florida, Amer. Meteor. Soc., 274–278.

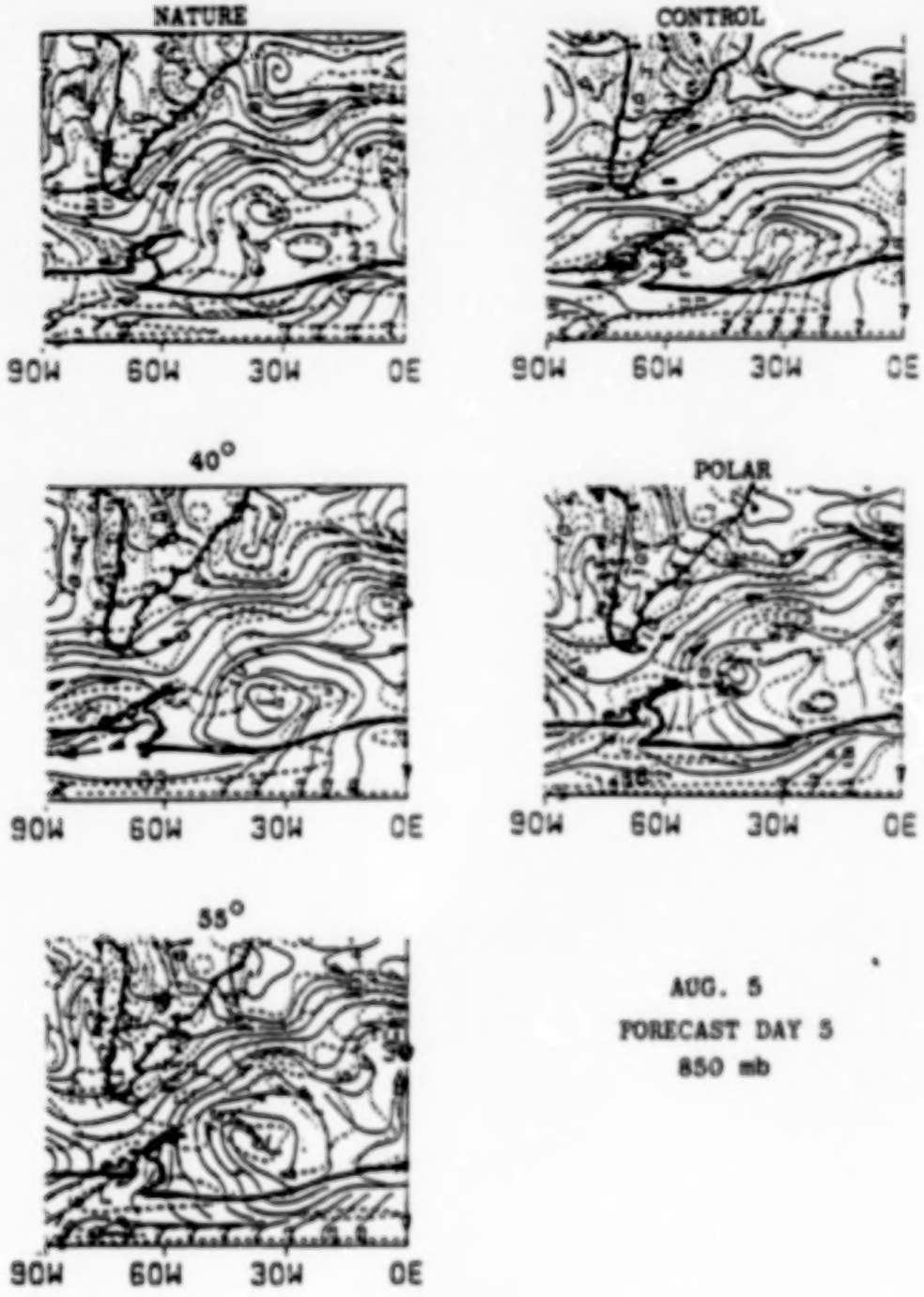

Figure 1a. The nature run shows a complex flow around the southern tip of South America. The control run, which contains WWW data only, shows a much too zonal wind field. This is due primarily to the lack of the WWW data over the South Pacific and Atlantic Oceans as well as the Scotia Sea. The other figures illustrate how different orbital inclinations affect the day five forecasts in this region. For the 40° and 55° inclination angle forecasts, the low pressure area is too large. The polar orbit shows a major improvement in the forecast of the low pressure area and the flow around it.

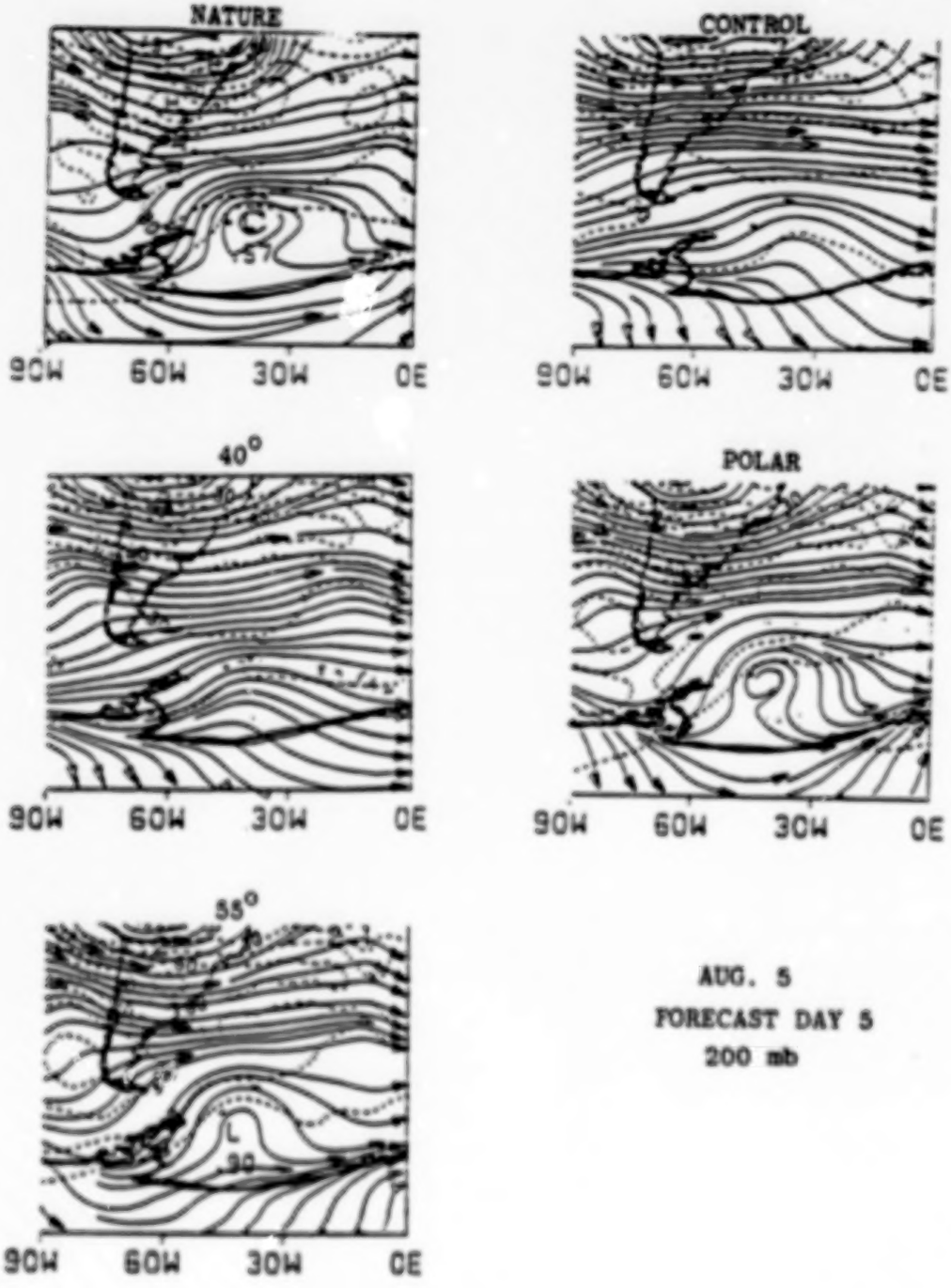

Figure 1b. The nature run shows a large upper level closed low. This feature is absent in the control run which gives a flow field which is too zonal. The 40° run does not contain enough information to better define the low pressure area. The 55° run begins to better pick up the wind field and makes the low much more pronounced. The polar orbit provides a wind field which looks much more like the nature and shows how this orbit will seemingly improve forecasting in the polar region.

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Title: Nonlinear Dynamics of Global Atmospheric and Earth-System Processes

Investigators:

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Barry Saltzman (PI)
Wesley Ebisuzaki (Postdoctoral Associate)
Kirk A. Maasch (Graduate Student/Postdoctoral Associate)
Robert Oglesby (Graduate Student/Postdoctoral Associate)
Lionel Pandolfo Graduate Student

Yale University, Department of Geology and Geophysics, P.O. Box 6666, New Haven, CT 06511

Significant Accomplishments:

During the past year we focussed on two major areas:

1) GCM Studies of the Atmospheric Response to Change Boundary Conditons. In a series of papers, listed below as publications (2, 4, 5, 6, 7), we report the results of an extensive series of numerical studies based on the NCAR-CCMI general circulation model. In these studies we have determined the response (a) to systematic changes in atmospheric CO_2 ranging from 100 to 1000 ppm, (b) to changes in the prescribed sea surface temperature (SST) in the Gulf of Mexico, such as occurred during the deglaciation phase of the last ice age, (c) to changes in soil moisture over North America, and (d) to changes in sea ice extent in the Southern Hemisphere. These latter three surface boundary conditions (SST, soil moisture, and sea ice coverage) are all measurable from systematic satellite observations. Among the significant results from these studies, we note the following: (i) It is shown that the response of surface temperature and other variables is nearly logarithmic, with lower CO_2 levels implying greater sensitivity of the atmospheric state to changes in CO_2, (ii) the surface temperature of the Gulf of Mexico exerts a considerable control on the storm track and behavior of storm systems over the North Atlantic through its influence on evaporation and the source of latent heat, and (iii) reductions in soil moisture can play a significant role in amplifying and maintaining North American drought, particularly when a negative soil moisture anomaly prevails late in the Spring.

2) Dynamics of Long-Term Changes in the Global Earth-System. Publications (3, 9, 10) listed below represent the first attempts to provide a unified theory for the onset and maintenance of the ice-age oscillations that emerged about 800,000 years ago. This work involves the consideration of complex nonlinear internal interactions between the atmosphere, hydrosphere, cryosphere, and bio-lithosphere that can combine under the influence of long-term radiative forcing due to earth-orbital (Milankovitch) variations to produce the most significant changes recorded in the earth-system. Of key importance is the role of atmospheric CO_2 as a forced and free variable.

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Focus of Current Research and Future Plans:

We have now undertaken the systematic study of the equilibria of GCMs as a function of initial and boundary conditions, with the aim of determining the transitivity or intransitivity of the GCM. Of particular interest are questions concerning the ultimate equilibration of a GCM when run for very long periods (say 100 years or longer), and the possibility that for similar boundary conditions multi-modal equilibria can exist.

More generally, we are continuing our analyses of large-scale dynamical models of the atmosphere to establish their sensitivity to satellite signatures of soil moisture, sea-surface temperature, snow cover, and sea ice in determining global weather variability.

Publications: (1990-1991)

1) Ebisuzaki, W., 1991: Vertical tilts of tropospheric waves: Observations and theory. *J. Atmos. Sci.*, in press.

2) Maasch, K. A., Oglesby, R. J., 1990: Meltwater cooling of the Gulf of Mexico II: A GCM simulation of climatic conditions at 12 ka. *Paleoceanography*, **5**, 977-996.

3) Maasch, K. A., Saltzman, B., 1990: A low-order dynamical model of global climatic variability over the full Pleistocene. *J. Geophys. Res.*, **95**, 1955-1963.

4) Oglesby, R. J., 1991: Springtime soil moisture, natural climatic variability, and North American summertime drought. *J. Climate*, in press.

5) Oglesby, R. J., 1991: A GCM investigation of the West Antarctic precipitation hole. *Antarctic Science*, in press.

6) Oglesby, R. J., 1991: The influence of sea ice extent on the Southern Hemisphere oceanic and atmospheric circulation. *EOS*, **71**, 1368.

7) Oglesby, R. J., Saltzman, B., 1990: Sensitivity of the equilibrium surface temperature of a GCM to systematic changes in atmospheric carbon dioxide. *Geophys. Res. Lett.*, **17**, 1089-1092.

8) Pandolfo, L., Sutera, A., 1991: Rossby waves in a fluctuating zonal flow. *Tellus*, in press.

9) Saltzman, B., Maasch, K. A., 1990: A first-order global model of late Cenozoic climatic change. *Trans. Roy. Soc. Edinburgh*, **81**, 315-325.

10) Saltzman, B., Maasch, K. A., 1991: A first-order global model of late Cenozoic climatic change II: A simplification of CO_2 dynamics. *Clim. Dyn.*, in press.

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TITLE: The Role of the Sea-Surface Temperature Distribution on Numerically Simulated Cyclogenesis During ERICA

N91-32688

INVESTIGATORS:

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SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

Many investigators have suggested that the warm waters of the Gulf Stream provide necessary energy for the explosive deepening which is a frequently observed characteristic of winter maritime cyclogenesis off the east coast of the United States and Canada. Data collected during ERICA (Experiment on Rapidly Deepening Cyclones over the Atlantic) held during the winter of 1988-89 affords the opportunity to investigate the effect of the Gulf Stream on well documented rapidly developing systems.

We know that the sea-surface temperature (SST) change across the north wall of the Gulf Stream is 10-15 ^{o}C in 5 to 20 km and that cyclone initiation was repeatedly encountered at the north wall on ERICA research flights. It is likely that the SST difference produces differential fluxes of heat and vapor into the atmosphere that form an atmospheric front in the boundary layer. The question is whether this atmospheric front significantly alters cyclone formation and movement.

The goal of this study is to quantify the extent to which a SST front can influence cyclogenesis. The approach is to use the Drexel Limited-Area Mesoscale Prediction System (LAMPS) dynamical model to simulate cyclogenesis over various SST fields. It is easy to specify various SST fields and show the differences they induce in the simulated cyclogenesis. However, the challenge is to specify the initial conditions of the large-scale flow and to insure reasonable initial adjustment to the specified SST field. If the initial boundary layer structure and the underlying SST field are significantly out of balance, unrealistically large initial heat and moisture fluxes may be produced as the boundary layer tries to reach "balance". This boundary layer "spin up" may obfuscate the results of sensitivity experiments designed to determine and understand the impact of the SST and boundary layer on rapid cyclogenesis.

Research during the past year has focused on the development and testing of a four dimensional data assimilation (FDDA) technique within LAMPS. The technique is a continuous dynamical assimilation where forcing terms are added to the governing model equations to gradually "nudge" the model solution toward a gridded analysis. In this study, nudging is used as a dynamic initialization tool during a 12 hour preforecast to generate model-balanced initial conditions for a subsequent 24 hour numerical prediction. Tests were performed to determine which variables to nudge and how to specify the four-dimensional weighting function used to scale the nudging terms. To this date, optimal results were obtained by nudging the u and v-components of the wind along with the potential temperature. The weighting function ranges form 0 to 1 and varies in time as a quadratic polynomial. It is initialized at 0, reaches its maximum at 9 hours into the preforecast and falls back to 0 at 12 hours. The nudging terms are included in the model equations for all grid points except those within the model predicted oceanic boundary layer. This design attempts to confine changes imposed by the specified SST field to the oceanic boundary layer during the preforecast period.

The scheme has been tested on a real data case of extreme cyclogenesis during ERICA on 4-5 January 1989. A model configuration with horizontal spacing of approximately 70 km and 20 vertical levels was used. The SST fields were identical in all experiments while testing the assimilation scheme. Results from three experiments are shown here. Two simulations were initialized at 12 UTC 3 January and integrated for 36 hours. One run included nudging during the first 12 hours while the other does not. The third simulation was initialized 12 hours later at 00 UTC 4 January and was integrated for 24 hours. Figure 1 shows that the simulation initialized 00 UTC 4 January produced a more intense system (curve B) than that produced when starting the model 12 hours earlier (curve A). The figure shows the success of the nudging technique which significantly improved the central pressure of the simulated cyclone in comparison with the 36 hour forecast without nudging (compare curves A and C). It is also worth noting that nudging also significantly improved the storm track (not shown).

Other tests were performed to determine the effect of various combinations of horizontal and vertical resolutions on the cyclogenesis. To this point, horizontal grid spacing of 140, 70, and 35 km have been used in combination with vertical resolutions of 1 and 0.5 km (20 and 34 vertical levels). It was found that the most significant improvement in deepening occurred when increasing the vertical resolution in the 70 km simulations. This was a surprising result considering that increased vertical resolution with horizontal spacing of 140 km had virtually no impact. Testing has just begun at 35 km with high vertical resolution and preliminary results show highly detailed precipitation patterns associated with the intense cyclone. Figure 2 shows the time evolution of the simulated total precipitation rate at 6 and 18 hours into the forecast from the 35 km run. Comparison between subjective analyses (not shown) and the precipitation patterns indicates the model successfully reproduced many of the mesoscale features associated with the event.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

The next phase of the work will be to complete testing of the nudging technique. Once testing is completed, a series of experiments will be performed using variations of the SST fields, such as elimination of the Gulf Stream, a weakened Gulf Stream SST front or idealized Gulf Stream fronts. These types of experiments will be performed on a number of ERICA cases. Other work includes comparison of the model simulations and SSM/I (Special Sensor Microwave Imager) observations to aircraft radar returns and in situ measurements of atmospheric temperature, moisture, wind and microphysics data. This will enable some verification of simulated vertical structure to the LAMPS condensate fields, and also help interpret more accurately the SSM/I data.

PUBLICATIONS:

Perkey, D.J., F.R. Robertson, W.M. Lapenta, and C. Cohen, 1990: Comparison of SSM/I measurements to numerically-simulated cloud and precipitation during ERICA. Preprints, 5th Conference on Satellite Meteorology and Oceanography, American Meteorological Society, September 3-7, 1990, London, England.

Perkey, D.J., W.M. Lapenta, F.R. Robertson, and C.W. Kreitzberg, 1991: The Role of the Sea-Surface Temperature Distribution on Numerically Simulated Cyclogenesis During ERICA IOP-4. Preprints, 1st International Winter Storm Symposium, January 13-18, 1991, New Orleans, LA.

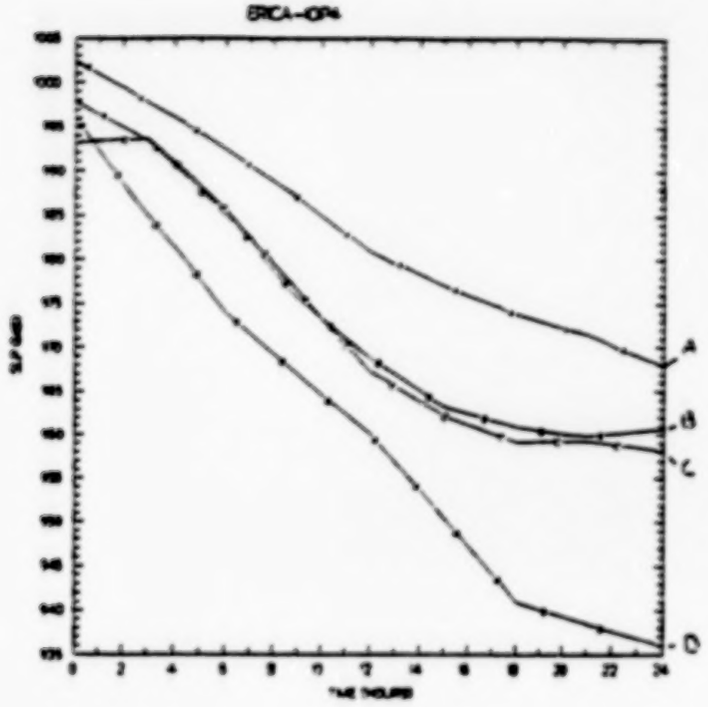

Figure 1. Comparison of model-simulated central pressure for the 36h no-nudging (curve A), 36h nudging (curve C) and the 24h no-nudging (curve B) versus time with observed central pressure (curve D) for the time period valid 00 UTC 4 January to 00 UTC 5 January 1989.0

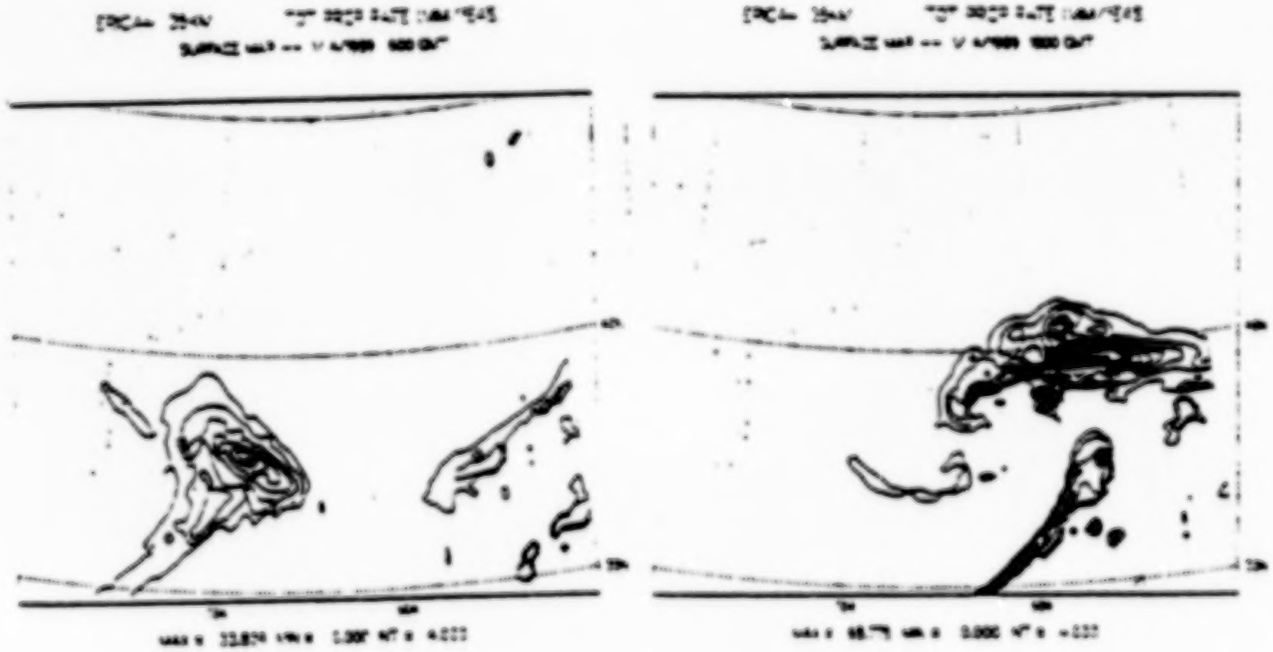

Figure 2. LAMPS total precipitation rate valid at 06 and 18 UTC 4 January 1989 (06 and 18 hours into model integration) for the 35 km run. Contour interval is 4 mm $(10^3 s)^{-1}$.4

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Monitoring, Analyzing and Modeling Global Climate

John R. Christy
University of Alabama in Huntsville

Research Activities June 1990 - May 1991

1. Diabatic Heating Rate Estimates

NASA Funding: 1988-90 Global Scale Processes; 1991- EOS

Christy, J.R., 1991: Diabatic heating rate estimates from European Centre for Medium-Range Weather Forecasts analyses. *J. Geophys. Res.*, **96**, 5123-5135.

2 Conference Preprints, 1 Workshop presentation

One year of Graduate Student support for Remata Reddy at UAH

Diabatic heating rate estimates as residuals of the dry thermodynamic equation have been generated for 1 May 1985-December 1989 in pentad resolution. Published results show moderate correlations (~.6) between heating rate and outgoing long-wave radiation for periods under 90-days in the tropics and many extratropical locations. Further work must await a systematic reanalysis of the base ECMWF data because discontinuities create spurious "climate changes".

2. Community Climate Model Simulations

NASA Funding: 1990 EOS; 1991 - proposed to modeling research

1 Conference Preprint, 1 Workshop presentation.

Nine years of simulation with the CCM1 using R15 and observed SSTs shows the model retains significantly more heat at the surface and in the free atmosphere than does the actual earth system. Current and future research will search for the reasons for the spurious warmth and seek to alleviate the problem. A post-processor for the CCM1 with capabilities to produce simulated MSU brightness temperatures was written by the investigator.

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3. Microwave Sounding Unit Brightness Temperatures

NASA Funding: 1990 Climate, 1991- proposed from Climate

Christy, J. R., 1992: Monitoring global temperature changes from satellites, *Global Climate Change: Implications, Challenges and Mitigation Measures*, S. K. Majumdar, L. S. Kalkstein, B. Yarnell, E. W. Miller and L.M Rosenfeld, Eds. Pennsylvania Academy of Science.

Spencer, R. W., J. R. Christy and N. C. Grody, 1990: Global atmospheric temperature monitoring with satellite microwave measurements: Method and results 1979-84. *J. Climate*, **3**, 1111-1128.

Spencer, R. W. and J. R. Christy, 1991: Precision and radiosonde validation of satellite gridpoint temperature anomalies, Part I: MSU channel 2. *J. Climate* (submitted).

Spencer, R. W. and J. R. Christy, 1991: Precision and radiosonde validation of satellite gridpoint temperature anomalies, Part II: A tropospheric retrieval and trends during 1979-90. *J. Climate* (submitted).

3 Conference Preprints, 5 Presentations

Operational cooperation with Climate Analysis Center (NOAA)

Techniques were refined considerably and validation studies were carried out to verify the globally distributed free atmosphere temperature anomalies derived from MSU data. The precision is such that detailed, long-term climate monitoring is well within the capability of these data.

4. MSU and Monitoring Global Climate

NASA Funding: small portion from Climate

Trenberth, K. E., J. R. Christy and J. W. Hurrell, 1991: Monitoring global monthly mean surface temperatures. *J. Climate* (submitted).

Hurrell, J. W. and K. E. Trenberth, 1991: An evaluation of monthly mean MSU and ECMWF global atmospheric temperatures for monitoring climate. *J. Climate* (submitted).

1 Conference Preprint, 4 presentations

In Trenberth et al., the lack of consistent correlations over the oceans between MSU and surface data was examined. Variances due to signal and error were

calculated for MSU and sea surface gridded anomalies. It was shown that surface anomalies for most of the ocean south of 20°N are not accurately known even in the present day.

In Hurrell and Trenberth, the global validity of the MSU was demonstrated and that discontinuities in the ECMWF data indicated false climate changes. Knowledge of the free atmospheric temperatures from the MSU is necessary as they monitor the levels that should show the signal of the anticipated enhanced greenhouse effect in the most unambiguous manner.

An investigation with J. Goodridge (retired state climatologist of California) has shown that for California, the stations monitored by the WMO and used in data sets such as GISS and East Anglia do not represent the actual long term temperature trends. This was shown by studying those WMO stations as part of the total 112 stations in the state. The median decadal trend of all 112 was +0.067°C while those of the stations used in long-term trend construction for GISS gave a +.150°C value. Given the fact that considerable urbanization has infected the California records, the true temperature trend is likely much less than the median +.067°C. Also note that GISS extrapolates values to 1200 km off-shore, so that warm-biased California data affect an area over five times that of the state's actual size. Further work will quantify the differences between many-station trends versus those of WMO stations.

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TITLE: Tropical Pacific Moisture Variability

INVESTIGATOR: James P. McGuirk
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RESEARCH OBJECTIVES:

1. To describe synoptic scale variability of moisture over the tropical Pacific Ocean and the systems leading to this variability.
2. To implement satellite analysis procedures to accomplish (1).
3. To incorporate additional satellite information into operational analysis/forecast systems at NMC.
4. To synthesize knowledge gained from satellite observations through diagnosis and numerical models.

SIGNIFICANT ACCOMPLISHMENTS IN FY 90/91:

1. Satellite data analysis. Three significant tasks were accomplished this past year. Additionally, a nearly complete study of the accuracy of ECMWF and NMC tropical analyses compared to observed satellite radiance fields has been put on hold while its author was assigned to Operations Desert Shield and Desert Storm.
   a. Comparisons of upwelling radiance fields for 1983 and 1984 were completed for the purpose of testing the sensitivity of water vapor/greenhouse feedback to local sea surface temperature variations.
   b. The interaction between tropical plumes, wave features over Central America, travelling waves in the upper tropospheric tropics and the tropical interseasonal oscillation was examined in OLR and TOVS tropopause level channels. Generally, little interaction occurs between these features (Winton's thesis).
   c. Planning and early efforts on construction of a model and infrared based climatology of daily precipitable water are completed. Methodology includes the split window technique, differential absorption, statistical regression and sensitivity testing using radiative transfer models.
2. Tropical plume mechanisms. Satellite data have been used over the last several years to improve classical diagnosis and modelling of tropical synoptic systems.
   a. Computations of the kinetic energy budget over a limited domain surrounding tropical plumes and for a global tropical strip reveal that global barotropic mechanisms and tropical-midlatitude interactions increase significantly, particularly at synoptic scales, when tropical plumes erupt in only a limited domain. NMC and ECMWF analyses are not adequate to resolve baroclinic mechanisms within plumes.
   b. A barotropic model, developed to examine wave-wave interaction of tropical normal modes, has been extended to run with a realistic upper tropospheric basic state. Forcing, simulating midlatitude troughs and surges in the tropical Walker circulation, generates many of the

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observed features within tropical plumes. Pressure-work terms dominate the development, but the atmospheric source of the work term cannot be identified in a barotropic model.

c. Results of integrations of the NMC Medium Range Forecast Model, using satellite enhanced initial conditions demonstrate the sensitivity to the basic state of the evolution of tropical synoptic scale waves. In two cases, tropical plume and vortex evolution were predicted more realistically using additional available TOVS observations. Model performance was improved only when the moisture field was adjusted in conjunction with height/temperature changes.

FOCUS OF CURRENT RESEARCH AND PLANS FOR FY 91/92:

1. Full documentation of tropical plume mechanisms (2a, 2b, and 2c) will take most of the next 6 months.

2. Barotropic model development and experimentation will continue. Design of a realistic El Nino-type basic state has commenced to examine ENSO/non-ENSO differences. Linearized and two-layer baroclinic versions of the model will be developed to resolved tropical plume mechanisms more precisely.

3. The major focus will be observation and analysis of tropical moisture fields from space. Item 1c above will near completion. Results will be a better understanding of the sensitivity of satellite infrared observations to tropical moisture fields and the reconstruction of historical precipitable water fields for comparison with SSM/I and future data sets.

4. Aspects of WetNet research (by McGuirk and Zipser) will be merged to examine the synoptic structure of tropical systems (plumes and cold surges) as viewed by SSM/I-derived moisture fields.

PUBLICATIONS (since August 1990):

Refereed:

McGuirk, J.P., and D.J. Ulsh, 1990: Evolution of tropical plumes in VAS water vapor imagery, Mon. Wea. Rev., 118, 1758-1766.

Presentations:

McGuirk J.P., and D.E.W. Smith, 1990: TOVS channel radiances as a "ground truth" for ECMWF analysis, Accepted for AMS 5th Conf. on Satellite Meteorology and Oceanography, London, September 1990.

_____, 1990: Use of satellite-derived spatial patterns in synoptic-scale numerical forecasts, op. cit.

_____, 1991: Long term climatology of precipitable water from space, WetNet Science and Analysis Colloquium, Santa Barbara, February 1991.

-----, 1991: Transient tropical-extratropical interaction observed and simulated in a barotropic model, Accepted at the IUGG/IAMAP Symposium on Large-Scale Atmospheric Flow and Variability, Vienna, Austria, August 1991.

-----, 1991: Improved satellite signals in tropical forecasts in the NMC Medium Range Forecast Model, submitted to the AMS 9th Conf. on Numerical Weather Prediction, Denver, October 1991.

-----, K.G. Blackwell and Y. Zhang, 1991: Divergently-forced transient tropical response in a shallow water model with a realistic basic state, submitted to the AMS 8th Conf. on Atmospheric and Oceanic Waves and Stability, Denver, October 1991.

Theses/ Dissertations:

Blackwell, K.G., 1990: Transient synoptic forcing of tropical plumes in a barotropic model with a realistic basic state, PhD., Texas A&M Univ., 269pp.

Lee, J.G., 1991: Comparative tropical synoptic scale kinetic energy budgets, PhD., Texas A&M Univ., (August 1991).

Winton, S.E., 1991: Eastern Pacific and Central American tropical systems as viewed from satellite, MS., Texas A&M Univ., (August 1991).

[Totaling 7 refereed publications, 35 conference papers, 11 MS. theses, 6 PhD. dissertations under 8 yrs. of NASA sponsorship, commencing April 1983.]

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NAS8-37127: South Pacific Convergence Zone and Global Scale Circulations (July 1987 - July 1991, with no cost extension)

NAG8-836: Observational and Modeling Studies of Heat, Moisture, Precipitation, and Global-Scale Circulation Patterns (July 1990 - July 1993)

Dayton G. Vincent, Purdue University: Principal Investigator
Franklin "Pete" Robertson, MSFC/NASA: Scientific Collaborator

A. Significant Accomplishments (August 1990 - May 1991)

Since the last review, which was held in August 1990, our research group has continued to move forward on a number of research topics. These include, but are not restricted to: (1) observational and modeling studies of relationships between tropical heat sources and subtropical jet streams; (2) the intraseasonal (30-60 day) oscillation near the equator; and (3) precipitation over the tropical oceans. Essentially, we have completed all tasks originally proposed under our NASA contract, NAS8-37127, which terminates in July 1991. Also, we initiated some of the tasks outlined in our present grant, NAG8-836. A list of our most significant accomplishments in the last year is now given.

1. Dr. James W. Hurrell completed his Ph.D. degree in August 1990 and is now employed as a research scientist at NCAR in Boulder, CO.

2. Mr. Ken-Chung Ko, a graduate research assistant on the project, completed his M.S. degree in August 1990 and is continuing on to work toward his Ph.D.

3. Mr. Robb Velasco, an undergraduate research assistant on the project, completed his B.S. Honors degree in May 1991 and will be pursuing an M.S. degree in the environmental area in Civil Engineering at Purdue.

4. Mr. Perry Ramsey, a Ph.D. student on the project, presented a paper at the Fifth Conference on Satellite Meteorology and Oceanography at London, England in September 1990.

5. Dr. Dayton Vincent attended the annual seminar series at ECMWF in Reading, England in September 1990. The title of the series was "Circulation Features of the Tropics and Interactions with Extratropical Latitudes: Observations and Modeling".

6. Dr. Dayton Vincent presented a paper at the Seventh Symposium on Meteorological Observations and Instrumentation in New Orleans in January 1991.

7. Dr. Dayton Vincent presented a paper at the 19th Conference on Hurricanes and Tropical Meteorology in Miami in May 1991.

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8. We received our new IBM PS/2 55SX computing system with a laser printer. It is being used to capacity by our project and, through its graphics capability, has greatly enhanced our research efforts.

B. Focus on Current Research

Presently, we are preparing for a busy summer of research activity. Dr. Vincent is working on two papers he will present at the IUGG meetings in Vienna, Austria in August 1991. One paper titled, "Mean monthly precipitation rates over tropical oceans", by Vincent, Velasco and North, will be given at the IAMAP Workshop on Precipitation Measurements, while the second paper, "The relationship between tropical heating and subtropical wind maxima", by Drs. Hurrell and Vincent, will be given at the IAMAP Symposium on Large-Scale Atmospheric Flow and Variability. Dr. Vincent is also working on a preprint paper, "Relationship between the intraseasonal oscillation and subtropical wind maxima over the South Pacific Ocean", by Dr. Hurrell and himself, which will be presented at the Fifth Conference on Climate Variations in Denver, CO in October 1991. Finally, Drs. Hurrell and Vincent are presently working on a revised version of their manuscript, "A GCM study on the maintenance of short-term subtropical wind maxima in the summer hemisphere during SOP-1, FGGE", which has been accepted for publication in the Quarterly Journal of the Royal Meteorological Society, subject to minor revisions.

C. Plans for Next Year

1. Prepare a final report for our contract, "South Pacific Convergence Zone and Global-Scale Circulations" (NAS8-37127), which terminates on 19 July 1991.

2. Travel to Vienna, Austria in August 1991 to present two papers and Chair a session at the IUGG IAMAP meetings.

3. Travel to Denver, CO in October 1991 to present a paper at the Fifth Conference on Climate Variations.

4. Prepare a manuscript to submit for publication on Mr. Ken-Chung Ko's research.

5. Prepare a manuscript to submit for publication on the paper being given by Dr. Vincent at Denver (item C-3).

6. Continue to make progress on the Ph.D. research of Messrs. Ramsey and Bourassa.

7. Prepare an Abstract to submit and, presumably, a paper to present, at the Third Symposium on Global Change Studies to be held in Atlanta, GA in January 1992.

8. Begin working with a new M.S. student on the project, Mr. Dave Sliwinski, who will join us in August 1991.

D. Publications (August 1990 - May 1991)

1. Refereed

Vincent, D.G., T. Sperling, A. Fink, S. Zube and P. Speth, 1991: Intraseasonal oscillation on convective activity in the tropical Southern Hemisphere: May 1984 - April 1986. Journal of Climate, 4, 40-53.

In addition, three other papers by our research group have been accepted for publication subject to revision, one to the Quarterly Journal of the Royal Meteorological Society (Hurrell and Vincent) and two to the Journal of Climate (Hurrell and Vincent; Vincent, North, Velasco and Ramsey).

2. Preprint papers

Hurrell, J.W. and D.G. Vincent, 1991: Observational and modeling study of the maintenance of short-term subtropical wind maxima in the Southern Hemisphere during SOP-1, FGGE. 19th Conference on Hurricanes and Tropical Meteorology, May 6-10, 1991, Miami, FL, 6 pp.

North, K.H. and D.G. Vincent, 1991: Precipitation rates in the tropics: June 1984 - May 1987. Seventh Symposium on Meteorological Observations and Instrumentation, January 14-18, 1991, New Orleans, LA, American Meteorological Society, Boston, MA, 189-194.

Ramsey, P.G., 1990: Diagnosis of tropical convection using the International Satellite Cloud Climatology Project (ISCCP) C1 data set. Fifth Conference on Satellite Meteorology and Oceanography, September 3-7, 1990, London, England, 2 pp.

3. Theses

Hurrell, J.W., 1990: Maintenance of short-term subtropical wind maxima in the Southern Hemisphere: Observational and modeling study. Ph.D. thesis, Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN, 47907, 161 pp.

Ko, K.-C., 1990: Baroclinic (shear) and barotropic (mean) kinetic energy study of Southern Hemisphere subtropical wind maxima. M.S. thesis, Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN, 47907, 54 pp.

Velasco, R., 1991: A diagnosis of moisture parameters in the tropics, including two estimates of precipitation rates. B.S. Honors thesis, Department of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN, 47907, 77 pp.

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Title: Synoptic/Planetary-Scale Interactions and Blocking Over the North Atlantic Ocean

Investigators: Phillip J. Smith (PI)
Mary A. Uhl (Project Assistant)
Anthony R. Lupo (Graduate Research Assistant)
Gregory L. Lamberty (Graduate Teaching Assistant)
Melinda Hunter (Undergraduate Assistant)

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Significant Accomplishments in the Past Year

The central theme of this project has been the diagnosis of a major blocking anticyclone and its interacting synoptic-scale circulations that occurred during January 1979 over the North Atlantic Ocean. Foremost among the interacting circulations was an extratropical cyclone that developed explosively 60 to 36 hours prior to the block's first appearance. One segment of our work this past year focused on the diagnosis of this cyclone and, in addition, the diagnosis of a second explosive cyclone development that occurred over the southeastern United States during the time of block formation. The diagnoses have been accomplished using a diagnostic relationship known as the Zwack-Okossi (Z-O) development equation, originally published in quasigeostrophic form in 1986 (Zwack, P., and B. Okossi, 1986: Monthly Weather Review, pp. 655-666). The PI has been collaborating with Dr. Zwack (University of Quebec at Montreal) to formulate an extended form of the Z-O equation that includes non-quasigeostrophic forcing. Results indicate, not surprisingly, that in both cyclone cases the development occurred as a result of the combined favorable influence of positive vorticity advection, warm air advection, and latent heat release and ceased when one or more of these influences diminished. Among the advantages of the Z-O equation is its ability to diagnose the influence of each atmospheric layer on surface development and, thus, fully expose the process synopticians refer to as "upper-air support". This study has revealed that much of the upper-air support occurs above 500 mb (maximum 300-200 mb) through the vorticity and temperature advection terms. Latent heat release maximizes below 500 mb. In addition to its use as a tool for diagnosing low level development, there is yet another dimension to the Z-O equation. It also provides near-surface height tendencies available for use as a lower boundary condition for the height tendency equation. This has been applied to upgrade height tendency estimates previously obtained for the over-water case and is described in a manuscript recently submitted to Tellus.

A second segment of our work has been the continued comparison of the SAT and NOSAT versions of the Goddard Laboratory for Atmospheres (GLA) 4° lat by 5° lon FGGE analyses. The comparison strategy has been to examine correlation coefficients, RMS differences, and standard deviations first for

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basic variable fields (e.g., geopotential height, temperature, wind speed) and then for higher-order derived parameters (e.g., gradient magnitudes, advections, vorticity, height tendencies). In all cases basic variable fields exhibit very high correlations (typically greater than 0.95), suggesting only subtle differences in the basic patterns given by the two analysis sets. However, RMS differences are as high as 30% of the basic variability of the fields, indicating that more significant point-to-point differences do occur. These differences then lead to decreased correlations as increasingly higher-order parameters are considered.

Focus of Current Research and Plans for Next Year

The present focus is on the completion of the two tasks identified in the previous section and the submission of appropriate journal manuscripts. In the coming year we expect to test the sensitivity of the Z-O equation results to second-order differencing by repeating some of the calculations using fourth-order differencing. In addition, we expect to examine the surface anticyclone development that occurred beneath the upper-air blocking event.

Publications

1. Refereed

Fosdick, E.K., and P.J. Smith, 1991: Latent heat release in an extratropical cyclone that developed explosively over the south-eastern United States. Monthly Weather Review, 119, 193-207.

Uhl, M.A., P.J. Smith, and A.R. Lupo, 1991: The diagnosis of a pre-blocking explosively-developing extratropical cyclone system. Submitted to Tellus.

2. Non-Refereed

The following papers were presented by the PI and appear in the Preprint Volume of the First International Symposium on Winter Storms, January 14-18, 1991, New Orleans, LA.

Smith, P., A. Lupo, and P. Zwack: Diagnosing Development, Part II: A Study of Rapid Cyclone Development Using Analyzed Data Fields.

Smith, P., and R. Knabb: A Diagnosis of Vorticity Fields Associated with an Explosively-Developing Winter Cyclone over the South-eastern United States.

3. M.S. Thesis

Lupo, Anthony R.: A Diagnosis of the Explosive Development of Two Extratropical Cyclones (May 1991).

AGENDA

NASA/MSFC EARTH SCIENCE AND APPLICATIONS PROGRAM

FY91 REVIEW

Tuesday, May 28, 1991
MSFC, Building 4481, Room 107

1:00	*Introduction and Welcome*	Ron Koczor
1:15	*Global Water Cycle*	Pete Robertson
1:45	*Theoretical and Experimental Studies of Baroclinic Processes*	Tim Miller
2:15	*Investigation of Surface-Atmosphere Interactions Using GCM's*	Dan Fitzjarrald
2:45	*Multi-Spectral Atmospheric Mapping*	Gary Jedlovec
3:15	*Passive Microwave Precipitation Studies/AMPR*	Roy Spencer
3:45	*Atmospheric Electricity Processes/LMS*	Hugh Christian
4:15	*Atmospheric Aerosol and Doppler Lidar Studies*	Jeff Rothermel
4:45	*Global Lightning Studies*	Steve Goodman
5:15	*Wetnet Operations*	Mike Goodman
5:45	ADJOURN	

Wednesday, May 29, 1991
Holiday Inn, Research Park

8:30	*Welcome and Introduction*	Einar Tandberg-Hanssen, Jim Arnold, Fred Leslie
8:45	*HQ Program Overview*	John Theon, Robert Schiffer, Jim Dodge, Ramesh Kakar,
9:00	*Scientific McIDAS Applications*	Paul Meyer
9:30	*Advanced Visualization Techniques*	Mike Botts
10:00	*4-D Visualization*	Bill Hibbard
10:30	BREAK	
10:45	*Research On Diabatic Initialization*	Arthur Mizzi (Kasahara)
11:15	*Potential Vorticity Index*	Hengyi Weng (Barcilon)

11:45	*Use of Satellite Data and Modeling to Assess The Influence Of Stratospheric Processes On The Troposphere*	Terry Nathan
12:15	LUNCH	
1:15	*Stratiform Clouds and Their Interaction With Atmospheric Motion*	John Clark
1:45	*Laboratory and Theoretical Models Of Planetary-Scale Instabilities and Waves*	Nick Brummell (Hart)
2:15	*Lightning in Winter Storms*	Marx Brook
2:45	*NOAA Backscatter Studies*	Madison Post (Hardesty)
3:15	BREAK	
3:30	*Advanced Doppler Lidar Techniques*	Gary Spiers (Bilbro)
4:00	*Backscatter Studies*	Richard Shotland
4:30	*Solid State Aerosol Backscatter Studies*	Milton Huffaker
5:00	*Radar Wind Sounder Simulations*	Tim Propp (Moore)
5:30	*VAS Humidity Studies*	Henry Fuelberg
6:00	ADJOURN	

Thursday, May 30, 1991
Holiday Inn, Research Park

8:30	*Global Temperature Variations*	Roy Spencer
9:00	*SSM/I Data Products*	Frank Wentz
9:30	*Airborne Imaging Spectrometer Applications*	Barry Rock
10:00	BREAK	
10:15	*Global Rainfall and Precipitable Water*	Ed Zipser
10:45	*Global Modeling and LAWS*	Gregg Rohaly (Krishnamurti)
11:15	*Satellite Doppler Wind Simulations*	Bill McCaul (Emmitt)
11:45	LUNCH	
12:45	*Boundary Layer Processes*	Dick McNider
1:15	*Microwave Radiative Transfer Studies*	J. Vivekanandan (Bringi)

1:45	*Nonlinear Dynamics of Global Atmospheric and Earth System Processes*	Kirk Maasch (Saltzman)
2:15	*Planetary Circulations in the Presence of Transient and Self-Induced Heating*	Harry Hendon (Salby)
2:45	BREAK	
3:00	*Mesoscale Research*	Mike Kalb and Bill Lapenta
3:30	*Global Scale, Intraseasonal Fluctuations of Diabatic Forcing of the Atmosphere*	John Christy
4:00	*Tropical Pacific Moisture Variability*	James McGuirk
4:30	*South Pacific Convergence Zone and Global-Scale Circulations*	Dayton Vincent
5:00	*Synoptic/Planetary Scale Interactions and Blocking Over The North Atlantic Ocean*	Phil Smith
5:30	ADJOURN	

The Following Appears On The Agenda Of Friday Participants Only

INFORMAL SPLINTER SESSION
With Available HQ Personnel

Friday, May 31, 1991
MSFC, Building 4481, Room 515

Suggested Topics
Robertson/Arnold (GEWEX)
Jedlovec (CAPE/STORM-FEST)
Leslie (ES42 SUMMARY)
Arnold (ES43 SUMMARY)
Hill (ES44 SUMMARY)
Koczor (DIVISION SUMMARY)
Theon/Schiffer (COMMENTS)

REPORT DOCUMENTATION PAGE

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13. ABSTRACT (Maximum 200 words)

This report summarizes the research presented at the annual Marshall Research Review of Earth Science and Applications. A large amount of attention has recently been given to global issues such as the ozone hole, tropospheric temperature variability, etc. A scientific challenge is to better understand atmospheric processes on a variety of spatial and temporal scales in order to predict environmental changes. Measurements of geophysical parameters such as wind, temperature, and moisture are needed to validate theories, provide analysed data sets, and initialize or constrain numerical models. One problem is that measurements are concentrated near large cities or airports of which virtually all are located on land (and mostly northern hemisphere) representing only a small part of the Earth's surface. One way to gain more understanding of the atmosphere is to make measurements on a global scale from space. One of NASA's initiatives is the Mission to Planet Earth Program comprised of an Earth Observation System (EOS) and the scientific strategy to analyze these data. This series of new sensors will measure globally (and in some cases, simultaneously) atmospheric parameters such as temperature, moisture, wind, lightning, etc. Analysis of satellite data by developing algorithms to interpret the radiance information improves our understanding and also defines requirements for these new sensors. This work describes these efforts in the context of satellite data analysis and fundamental studies of atmospheric dynamics which examine selected processes important to the global circulation.

14. SUBJECT TERMS

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